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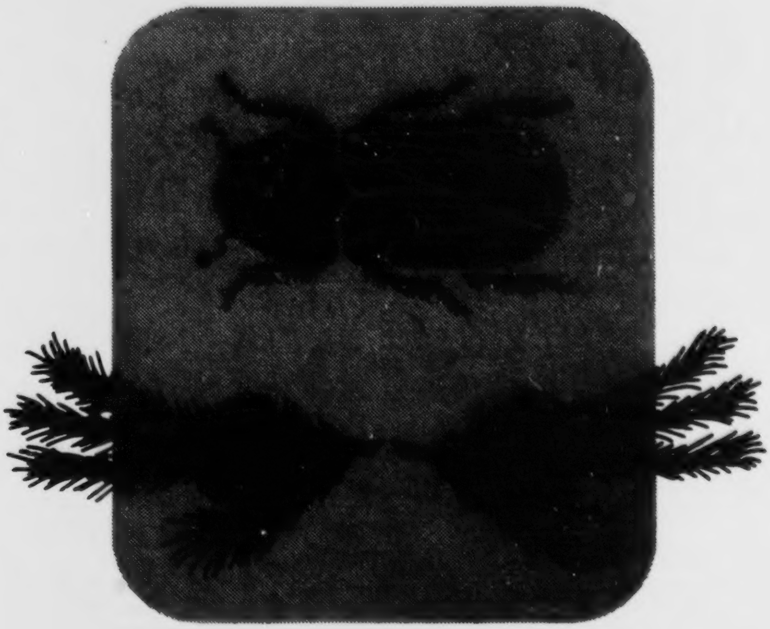
MOUNTAIN PINE BEETLE SYMPOSIUM PROCEEDINGS

Smithers, B.C., 1985



PEST MANAGEMENT REPORT NUMBER 7

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PROCEEDINGS OF THE MOUNTAIN PINE BEETLE SYMPOSIUM

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PREFACE

Mountain pine beetle has been the most serious forest insect problem in the Province of British Columbia since the early 1970's. Infestations have occurred in diverse forest zones of the province, from the southeast corner to the northwest areas. These infestations have necessitated redirection of harvesting, implementation of extensive aerial and ground surveys, and various single tree treatments to slow the rate of spread of infestations and to allow more long-term management programs to be put in place.

The insect, it's potential for further damage, and management approaches in British Columbia have been of great interest and concern to foresty practitioners in government agencies and the forest industry. A symposium was organized in April, 1985, to provide a forum for discussion which would disseminate state-of-the-art information to those actively dealing with problems resulting from mountain pine beetle, particularly those problems in northwestern British Columbia.

These proceedings are the result of this symposium. Over 150 people attended the symposium to listen to and discuss problems with a wide variety of specialists and managers from universities, provincial and federal governments, and industry. Topics ranged over a spectrum of beetle-related issues including biology, detection, operational options, and economics. The information contained in these proceedings will provide a sound basis to further refine lodgepole pine management practices which will reduce future losses to the mountain pine beetle.

ACKNOWLEDGEMENTS

The Smithers mountain pine beetle symposium attracted wide attention and interest by forestry practitioners in British Columbia, Alberta, and the United States. Careful planning and preparation of a symposium of this scope are key elements in the success of such an undertaking, particularly in terms of designing the agenda, organizing and co-ordinating speakers, and providing adequate facilities for the symposium. Although many people aided in making the symposium a success, special appreciation must be directed toward the following: P. Pashnik, G. Lloyd, M. Geisler, and G. Stahl (B.C. Ministry of Forests); and, T. Maher (Northwood Pulp and Timber Ltd., now with the B.C. Ministry of Forests). Without their dedication and energy, the symposium would have been much less than it was.

Further, those presenting papers in the various panels must be thanked. The quality of the information contained within these papers is indicative of the high degree of expertise of the speakers. Without them, the symposium could not have been held.

INTRODUCTORY REMARKS

K. J. INGRAM[1]

On behalf of the Prince Rupert Forest Region, it is my pleasure to welcome you to the first Mountain Pine Beetle Symposium to be held in Smithers. From the large numbers that are in attendance, I am confident that a symposium of this nature is both timely and beneficial.

The Pacific Northwest has a serious mountain pine beetle (MPB) infestation. It is particularly serious in the northern interior of this province. While initially, the Forest Service may have been somewhat complacent as to the potential damage and losses that could be expected from the first signs of MPB attack, I can assure you this reality now is well known. The expectation that the MPB would not be a serious threat to our Northern forest stands because of expected winter mortality has not proven true. Although at first complacent, the province and industry are now spending millions of dollars annually on control measures. In the 1984 fiscal year, an additional 5 million was allocated as an emergency fund for insect control. Of the 5 million special funding some 3.7 million was directed at beetle control projects in the northern interior. Special pest management funding is also to be provided for 1985. I understand approximately 7 million dollars has been earmarked for the bark beetle program. While I know that both Industry and the Forest Service had requested significantly more than this amount, the fact that the allocation is being increased is encouraging.

We are spending considerable time, effort and dollars in our attempt to control MPB in the interior of this Region. I believe the money has been well spent from the results of the control measures I have seen to this date. I also believe that the risk to our mature pine forests from the MPB is too great not to expect expenditures of this order for the purpose of control. In this Region alone, it is estimated that although 33,000 hectares were described as being infected during 1984, some 30 million m^3 were considered at risk to infection.

As previously mentioned, I believe the MPB control measures conducted in this Region have proven effective. The control program, I can assure you, is not the result of a "One Man Forest Service Band." Rather, it has been the combined effort of all licensees and the Forest Service in carrying out the ongoing planning, detection, lay-out, and operational facets of control activities. Without this 100% co-operation that has been given by the logging sector, I believe our success to date would be significantly less.

---

[1] K. J. Ingram, Regional Manager, Prince Rupert Forest Region, B. C. Ministry of Forests

The purpose of this Mountain Pine Beetle Symposium is to permit operational people the opportunity to exchange ideas and discuss methods and recent results of insect control. Through this dialogue and idea exchange, I am sure our efforts to control forest insects can only benefit.

OPENING REMARKS

D. R. Macdonald[1]

I have been asked to say a few remarks on behalf of the Canadian Forestry Service in regards to our involvement with the mountain pine beetle (MPB). I have been heavily involved in the co-operative Forest Resource Development Agreement between the B. C. Provincial Government and the Federal Government of Canada and am pleased that both parties have maintained some direct delivery dollars. It is encouraging that within this agreement there has been a significant level of funding devoted to the bark beetle problem.

Times have certainly changed in regard to our appreciation of pest problems. The last conference on MPB was in November, 1981 at Fairmont Hot Springs. I notice several of the same faces here today such as Les Safranyik, Gene Amman, Mark McGregor and others. The result of that meeting was a Canada/U.S. Memorandum of Understanding on the management of lodgepole pine and MPB problems. We shall be learning quite a bit about the complexities of the MPB problem over the next two days, not only the complex biological and ecological issues but also the sociological and economical factors which impose upon and constrain our responses. We must deal with markets, interest rates and future timber supplies, as these factors affect how we manage both the resource and the insect.

Back in 1981 at Fairmont Hot Springs, Max Peterson (Chief, U.S.D.A. Forest Service) and Les Reed (Assistant Deputy Minister, Canadian Forestry Service) and others explored the MPB problem and became convinced of the significance of the problem. However, no-one could foresee what the market forces of the past few years would do to the ability to control MPB and the management of lodgepole pine.

We've all got a tough job and the number of people coming to this symposium illustrates the concern over the MPB problem. Scientists from both the government and universities will do all they can to help you, but they need your support and co-operation. The sessions should be productive and I trust that the information brought forward during this symposium is of benefit in the implementation of an effective management program.

---

[1] D. R. Macdonald, Director General, Pacific Yukon Region, Canadian Forestry Service, Pacific Forestry Centre

STATUS OF MOUNTAIN PINE BEETLE

STATUS OF MOUNTAIN PINE BEETLE WITHIN NORTHWEST BRITISH COLUMBIA

B. D. Downie[1]

In my presentation today, I will relate the historical mountain pine beetle (MPB) infestations within the Prince Rupert Forest Region to previous control efforts, and provide a summary of the current infestation and control efforts. However, I will begin with the importance of lodgepole pine to the northwest forest economy.

The mountain pine beetle, Dendroctonus ponderosae, is the most damaging agent to the northwest interior's important commercial tree species, lodgepole pine, Pinus contorta. Lodgepole pine accounts for 47% of the operable mature forests in the interior of the Prince Rupert Forest Region. Within the Sub-Boreal Spruce Biogeoclimatic Zone, the total operable mature forest of lodgepole pine, spruce, Picea glauca x englemanii, and balsam, Abies lasiocarpa, amounts to 256 million cubic meters with an annual allowable cut of 4.5 million cubic meters to sustain 9 major sawmills, and generate much of the residual fibre for 4 pulp mills. The forest industry employs 1500 sawmill and 1200 woods employees in ten communities of the northwest. The threat to the lodgepole pine forests is recognized as a significant threat to the long term sustainability and viability of the interior forest industry.

History of MPB in the Northwest

The initial records of MPB infestations in the Prince Rupert Region are from the Canadian Forestry Service in 1949. Subsequent outbreaks occurred from 1953-59, 1961-64 and 1969 to the present. The earliest infestations were in the Kitwanga and Babine Lake areas.

In 1972, dramatic increases in infestations in the Kitwanga/Hazelton area and spreading to the Smithers area led to the first extensive MPB control program. By 1974, Smithers, Houston and Burns Lake forests were the focus of our detection, control logging and monitoring efforts. Logging operations were directed into current (green-attacked) stands to minimize subsequent flights. To facilitate the removal of infested timber, the Forest Service developed a log debarker and chipper facility to process small wood and excess volumes from infested stands. By 1977, the major infestations were considered "under effective control" with follow-up treatments mainly required.

---

[1] B. D. Downie, Forestry Manager, Prince Rupert Forest Region, B. C. Ministry of Forests.

During 1978, though, a severe windthrow event throughout the interior eventually resulted in widespread spruce beetle, Dendroctonus rufipennis, epidemics and redirected our pest management efforts to spruce beetle control. The extent of the spruce and mountain pine beetle operations were greatly in excess of the industry's ability to log and manufacture the infested stands. Consequently by 1981, the mountain pine beetle epidemic levels had dramatically increased to current day populations.

At this time, the recognized potential impacts of MPB resulted in a substantial (11.4 million dollars) emergency appropriation of provincial funds from the newly-created Forest and Range Fund. The MPB epidemic was estimated at 9,000 ha and 2.5 million cubic meters, with another 42 million meters potentially at risk (Table 1). Coupled with an additional 15,000 ha of spruce stand under attack by spruce beetle (SB), an intensive detection program was implemented to more effectively provide priorized logging control pans. On the basis of aerial and ground detection efforts, regional and district strategies were implemented for maximum infested stand removal and sanitation programs. The key involvement of industry in district and regional control plans is recognized as a significant part of the success of this program.

Although supplementary funding in 1982-83 was inconsistent, much of the logging in the interior was maintained in MPB priorities. However, with reduced detection emphasis, logging and infested volumes increased, resulting in reduced control effectiveness.

In 1984, emergency funds again enabled accelerated detection, more effective logging and a dramatic increase in single tree treatments and removal of small patches of infested trees.

Current Status of MPB in the Northwest

The current estimate of MPB infestation within the Prince Rupert Forest Region is 34,000 ha and 7.2 million cubic meters under attack. Approximately another 30 million cubic meters are considered at risk. Major control operations continue in the Smithers, Houston and Burns Lake areas as a result of: a) the importance of lodgepole pine to the interior harvest profile; and b) the expectation of success of the

TABLE I. PRINCE RUPERT FOREST REGION
BARK BEETLE STATUS AND CONTROL ACTIVITIES
1982-83

Forest District	Infested Area (Ha)		Potential Losses (m^3)		Area Harvested	Single Tree Disposal	Trap Trees	Ground Surveys & Probes (Ha)	
	MPB*	Spruce**	MPB	Spruce		TOTAL TREES	TOTAL TREES	MPB	SPRUCE
LAKES	1,081	4,485	19,750,000	9,700,000	1,474	774	180	20	900
MORICE	2,949	2,008	3,000,000	7,500,000	2,500	2,074	7,557	500	2,500
BULKLEY	1,698	2,671	17,620,000	—	1,580	2,381	1,100	1,000	2,000
KISPIOX	1,500	270	317,000	5,000,000	487	280	Nil	800	200
KALUM	1,916	5,500	900,000	6,000,000	150	230	2,000	Four hours aerial only	
TOTAL	9,135	14,934	41,587,000	28,000,000	6,191	5,739	10,837	2,590	5,600

* Mountain pine beetle

** Spruce beetle

Prepared by: V. Barge, Prince Rupert Forest Region, Smithers.

interior control programs based upon the size and historical rate of spread of the infestations.

Present Control Strategies

a) Harvesting

The primary method of control of MPB is to date, and will continue to be, the logging of mature currently attacked stands. Guided by aerial sketch maps, colour aerial photography and ground surveys, logging is directed to the most intensely infested stands within each timber supply area. Industry participates in strategic control plans to priorize extensive road construciton and logging programs. Every infestation center receives a control decision and may be logged, single tree-treated or monitored for subsequent treatments.

During 1984, substantial efforts were made by the industry to specifically harvest the infested trees, leaving logical units of uninfested pine stands for follow-up treatments. Of critical importance was to extend operations to deal with as much infested material as possible and minimize, within the maximum mill capacity, the mill consumption of uninfested trees. Further logging emphasis upon green attacked stands (rather than red or grey stands) similarly resulted in maximum impact upon the beetle populations. Greater than 70% or more than 3 million cubic meters over 10,000 ha of the Prince Rupert interior logging was in current attacked MPB stands.

b) Single Tree Treatments

1. Fall and Burn

Due to the extent of the infestation and the distribution of attack centers, isolated pockets of infested pine are not effectively controlled by logging. Furthermore, logging is priorized towards the heaviest concentrations of attack. Consequently, an important control strategy for MPB is an agressive fall and burn treatment program designed to impede the build-up of attack centres until such time as access and logging can reach the area. Isolated, inaccessible infestations are similarly priorities for single tree treatments.

An integral phase of the fall and burn project is the peeling of stumps to eliminate residual beetles.

During 1984-85, fall and burn treatments on 28,000 trees was completed at any average cost of $25.00 per tree.

2. Brood Removal

For larger groups of infested trees, a selection logging system is employed to extract the brood trees and recover the lumber value. During 1984-85, 49,000 infested trees were removed by this method.

3. Pheromone Placement

Pheromone attractants are now widely used in the interior to concentrate the residual beetle attack on baited trees following fall and burn or harvesting treatments. Pheromone-baited traps monitor MPB flights to minimize the log hauling restrictions to the critical flight periods.

4. Chemical Beetle Control

Minimal MSMA and carbaryl chemical treatments have been implemented to date, although more are planned for 1985-86.

5. Prescribed Burning

In critical, inaccessible infestations where unchecked infestations will threaten the surrounding pine stands, prescribed burning may be a viable MPB control treatment. One experimental prescribed burn at Bristol Lake near Smithers was completed in 1983 and was considered cost effective compared to fall and burn treatments and was completely successful in destroying the brood.

In the foregoing summary of the Prince Rupert Forest Region's MPB infestations and control efforts, I have described the forest industry and forest service co-operative and agressive efforts to minimize the forest volume lost to MPB. I hope that with this perspective, the panel presentations following will stimulate our thinking to improve upon current practices.

THE MOUNTAIN PINE BEETLE SITUTAION IN BRITISH COLUMBIA, 1984

G. A. VAN SICKLE[1]

Past Infestations

The mountain pine beetle (MPB) continues to be the most damaging forest insect in British Columbia. Mature lodgepole pine are by far the most commonly affected tree species, followed by western whitepine, occasionally ponderosa pine and other pines, and rarely other species.

Outbreaks have been recorded at varying geographic locations within British Columbia at irregular intervals since at least 1910. Particularly notable early infestations occurrred in the Princeton, Okanagan Valley and Lillooet areas, and:

> from 1930-36 vast areas were infested around Tatla Lake and the Chilcotin in central British Columbia;
>
> from 1930-43 large infestations included the Kootenay, Yoho and Banff National parks;
>
> from 1953-65 infestations were around Babine and Takla Lakes in Northcentral British Columbia and in western white pine stands on Vancouver Island;
>
> from 1972-77 virtually all mature pine on more than 20,000 ha were killed in the Kleena Kleene Valley. When first reported in 1976 in the Flathead River Valley, localized pockets totalled 44 ha, but it spread and intensified to cover 15,000 ha by 1980.

Current Infestations

The current outbreaks started during the late 1960's and early 1970's. In 1974, a total of only 3,300 ha at 35 scattered locations were affected. This included small stands in the Elk Creek and White River valleys, the Okanagan, Quesnel Lake, Riske Creek and Kleena Kleene, and in the Prince Rupert Region near Kitwange, Hazelton, Kispiox and, again, Babine Lake. The infestations expanded and intensified rapidly (Figure 1). Since 1972 infestations developed and expanded and the area of newly red trees (often called faders) increased each year with very rapid increases in the early 1980's. Cumulatively, well over 185

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[1] G. A. Van Sickle, Forest Insect and Disease Survey, Canadian Forestry Service, Pacific Forestry Centre.

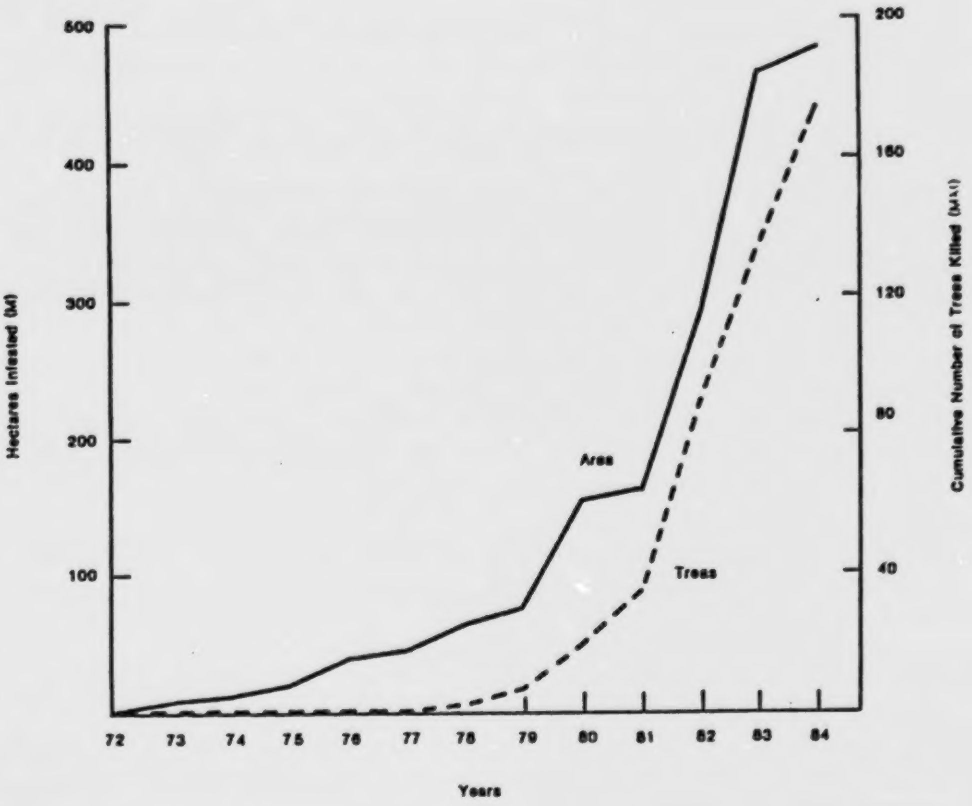
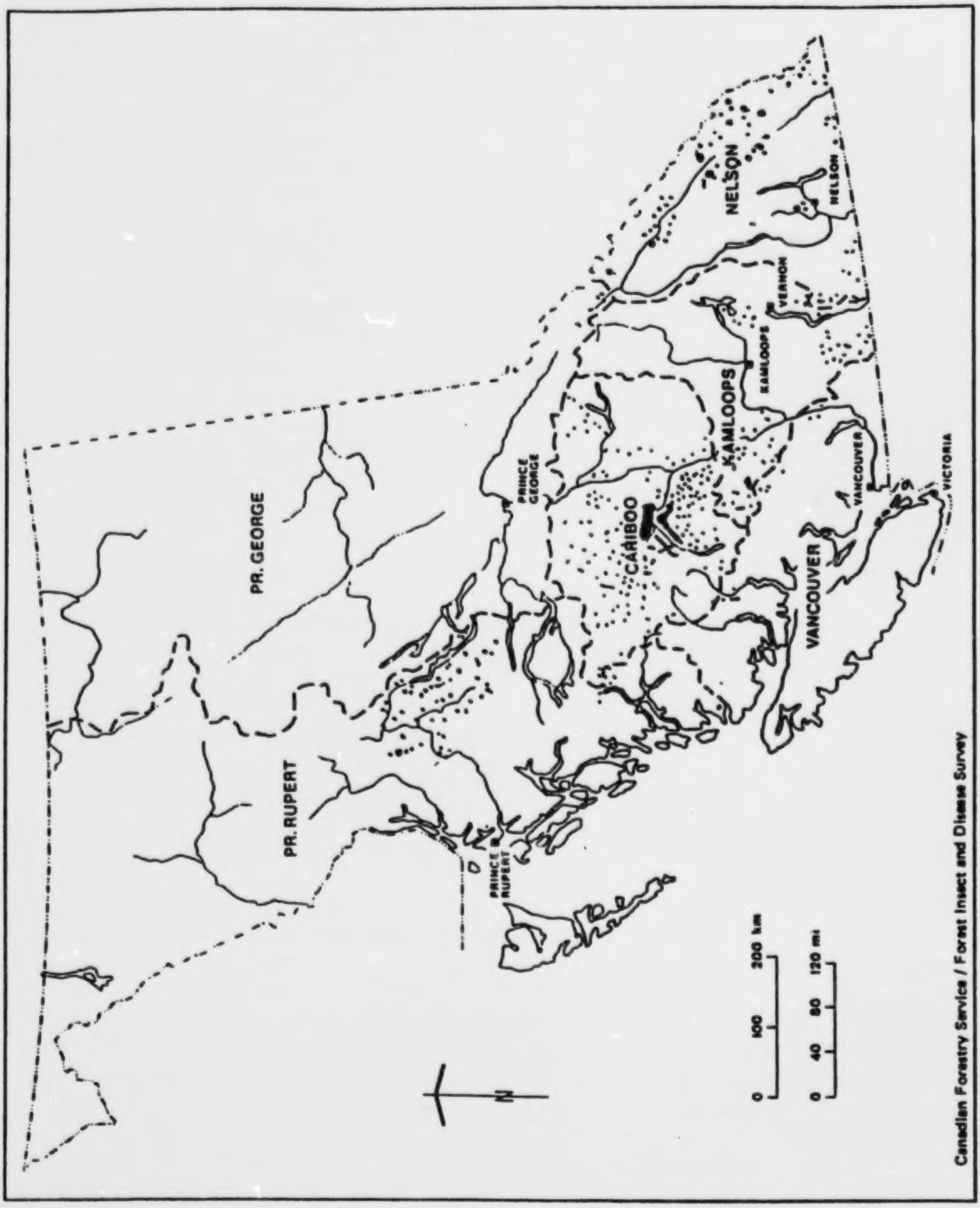


Figure 1. Lodge pole pine mortality caused by MPB in British Columbia.

million mature pine have been killed by the beetle throughout the province.

By 1984, heavy mortality of mature pine trees occurred in more than 7,000 separate locations covering more than 480,000 ha in the interior of British Columbia (Figure 2). It is estimated that the 1983 attacks alone killed more than 41 million trees, with a gross volume of 12 million m^3.

Aerial surveys in 1984 showed red trees (that is generally those killed in the past year) present over more than 480,000 ha in British Columbia. This represents more than three times the total area logged of all tree species in a year in the province. In individual forest regions, such as Cariboo, the area with recent kill is 16 times the area of annual harvest. Not included in these estimates are the additional areas of more than 170,000 ha where most of the mature pine have been dead for several years.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100
200 km
0
40
80
120 mi

Canadian Forestry Service / Forest Insect and Disease Survey

Figure 2. Areas where recent tree mortality due to MPB was detected during aerial surveys, 1984.

The cumulative loss to date and the potential loss - considering the extent and volume of the mature susceptible stands - are many times greater. Lodgepole pine is widely distributed throughout British Columbia, covering more than 14 million ha. Numerous mapped infestations are still relatively small in area and susceptible host remain in or near the attacked stands. The potential is high for continued spread and intensification in many areas.

In considering this information, it should be remembered that the maps and area or tree mortality estimates are based only on newly faded trees, most of which were attacked the year preceding the annual aerial surveys. Foliage on trees attacked late in the summer of one year generally does not turn the characteristic bright red until July of the next year. Recently killed trees that are still green, or trees killed in earlier years are not reflected in the annual data. Infestations generally persist within individual stands for eight or more years or until the pine component of the forest is depleted, especially the larger (more than 25 cm dbh) trees. Results from ground cruises may more clearly indicate average stand conditions. An overall provincial average, based on 50 infested stands cruised last fall, indicated that:

a) 10% of the trees were red, having been attacked and killed in 1983;

b) 17% of the trees were still green but fatally attacked, indicating a still expanding and increasing infestation;

c) 9% of the trees had been killed from attacks prior to 1983;

d) 4% of the trees were partially attacked and may survive, if only to be reattacked; and,

e) 60% of the trees, usually smaller trees, were as yet unattacked.

However, the variation among stands is extreme. The percentage of currently attacked trees ranged from 1 to 65, and in some stands that had been infested for as few as four years, less than 10% of the trees were still alive.

In summary, the mountain pine beetle, a native pest, is currently epidemic in lodgepole pine and some white pine stands throughout

Northwestern, Central and Southern British Columbia. Recent tree mortality is continuing on more than 480,000 ha of forest land. Older, almost complete stand mortality, most of which is unsalvageable, covers more than 170,000 ha. And, worst of all, most infestations are expected to expand and intensify in 1985.

QUESTIONS

QUESTION: Could you mention the eastward spread into the pine stands in Vanderhoof and Fort St. James, which at present, I understand, have very low levels of pine beetle.

BRIAN DOWNIE: There is an eastward progression of pine beetle. The Vanderhoof/Prince George Region is subject to mountain pine beetle spread from the Cariboo. At this point, Prince George Region is getting quite concerned about their southern boundary and the initiation of the salt and pepper effect - the leading edge of the infestation.

QUESTION: What was felt about the potential for mountain pine beetle in this area when the problem first arose.

AL VAN SICKLE: Concerns were expressed, certainly, but I think we also have to put in perspective that back at that time lodgepole pine occupied or was being utilized at about 1 or 2% of the provincial cut - quite a different situation from now, where it ranks either second or third, so while the Canadian Forestry Service and others were expressing some concerns there weren't too many people listening.

PANEL 1 - BIOLOGY OF THE BEETLE

EFFECT OF CLIMATIC FACTORS ON DEVELOPMENT, SURVIVAL, AND LIFE CYCLE OF THE MOUNTAIN PINE BEETLE

L. SAFRANYIK[1]

Introduction

Climate and weather are constantly present factors in the life of the mountain pine beetle (MPB). The dominant roles of these factors in determining population and damage levels are generally recognized by most forest entomologists and others concerned with forest protection. Of the climatic variables, temperature, wind, relative humidity, precipitation and light are the most important and affect MPB populations in two ways: a) directly, through the behavior and physiology of individual beetles and, b) indirectly through the host trees.

During the past three decades a great deal of information accumulated regarding both the direct and indirect effects of climatic factors on MPB population biology, especially on the effects of temperature. This information has been reviewed recently by Safranyik (1978). However, there is a need to relate this information to variations in the life cycle, distribution and abundance of the beetle. The purpose of this paper is to briefly explain the most important effects of climate and weather on MPB populations and of the timber losses caused by them. Readers seeking more detailed information are referred to Amman and Cole (1983). Amman *et al*. (1977), Safranyik (1978) and other references cited in this review.

Climatic Limits and Optima for MPB Activity

Of the climatic variables, temperature is the most important for MPB because adult emergence and dispersal, brood establishment, development and survival are all temperature-limited. The temerature limits of MPB activity are summarized in Table 1.

---

[1] L. Safranyik, Research Scientist, Canadian Forestry Service, Pacific Forestry Centre.

TABLE 1. Estimated temperature limits and optima for brood establishment, development and survival of the mountain pine beetle.

Event	Temperature range (°C)	Optimum temp. range (°C)
Adult emergence	16.0 - ?	20.0 - 30.0
Flight	19.0 - 41.0	20.0 - 32.0
Egg gallery construction and oviposition	1.7 - ?	20.0 - ?
Egg hatch	4.4 - 35.0	21.0 - 25.0
Larval development	2.2 - ?	?
Pupal development	10.0 - 30.0	?
Adult development	15.0 - 30.0	20.0 - ?
Dev. from egg to adult	15.0 - 30.0	20.0 - 26.0
Cold hardness:		
a) eggs	ca. - 18.0	NA[a]
b) larvae	-34.0 - 38.0	NA
c) pupae	higher than for adults	NA
d) adults	higher than for larvae	NA
High temperature tolerance (all stages)	38.0 - 43.3	NA

[a] NA = not applicable

Ambient temperatures play a major role in determining the onset and duration of the flight period and diurnal flight activity. Generally, emergence and flight periods are preceded by warm, dry weather but there appears to be no relation between the duration of this type of weather and the onset of emergence by the new adults. Temperature conditions during brood development play a major role in determining the length of the life cycle, hence, apparently, the onset of emergence and flight periods (McCambridge 1964, Reid 1962a). Daily emergence begins in the morning when air temperature reaches about 16°C and ceases in the afternoon at the same temperature (Reid 1962a, Rasmussen 1974). However, maximum emergence and flight activity usually occur when air temperatures exceed 20°C. In British Columbia and Washington maximum flight activity is usually in the period from 11:00 am to 4:00 pm (Gray _et al_. 1972, Reid 1962a). Emergence and flight are reduced at high temperatures. In the field, Gray _et al_. (1972) and Rasmussen (1974) found that emergence and flight activity were reduced at temperatures of 32°C or greater. In the laboratory, McCambridge (1971) has shown that flight is severely restricted above 38°C. In addition to temperature, precipitation has a major effect on the rate of emergence and the flight period since during rainy days beetles remain in the brood trees (Rasmussen 1974).

There has been little work done on the effect of weather on the processes of host colonization (i.e., establishment of initial attacks, aggregation of both sexes at, and mass attacks on, the host trees). Beetles arriving at dusk when temperatures are too low for boring activity conceal themselves overnight in bark crevices and commence boring into the bark next morning when air temperature reaches about 17°C (Rasmussen 1974). Egg gallery excavation and egg laying are determined, in large part, by temperature and moisture conditions. The lower temperature limit for boring and oviposition is near 1.7°C (Reid 1962b). Both the rate of egg gallery construction and oviposition increase curvilinearly with temperature (Amman 1972). The upper temperature limits for boring activity and egg laying have not been investigated. In lodgepole pine, oviposition by MPB ceases when the moisture content of the inner bark and outer sapwood drops below ca 105 and 60% oven dry weight, respectively (Reid 1962b). Under drier conditions, female MPB tend to abandon the gallery and re-emerge to make a second flight and attack.

Egg hatching occurs between 4.4 and 35°C (Reid and Gates 1970). In the laboratory, the optimum temperature range for egg hatch was 21 to 25°C

(Reid and Gates 1970). The low temperature threshold for larval development is near 2.2°C (McCambridge 1974). Near this threshold, the rate of development is inversely related to larval instar (Amman and Cole 1983). Amman and Cole (1983) and Safranyik and Whitney (1985) found that MPB broods reared at constant temperatures failed to pupate at 10 and 15°C, respectively. All MPB broods reared at constant 30°C died before completing pupal development (Amman and Cole 1983) and all larvae died within a few days of hatching at constant 32 and 35°C (Safranyik and Whitney 1985). Within the temperature range that occurs during the growing season in B. C., developmental time decreased with increasing temperature (Figure 1). Optimum constant temperature for brood development from egg to the adult stage is near 24°C (Safranyik and Whitney 1985). Under laboratory conditions survival was highest at this temperature (Figure 2). At constant 24°C, 674 degree-days (a degree-day is 1°C degree above the threshold temperature for 24 hours) above 5.6°C were required for development from egg to the tanned (dark) adult stage.

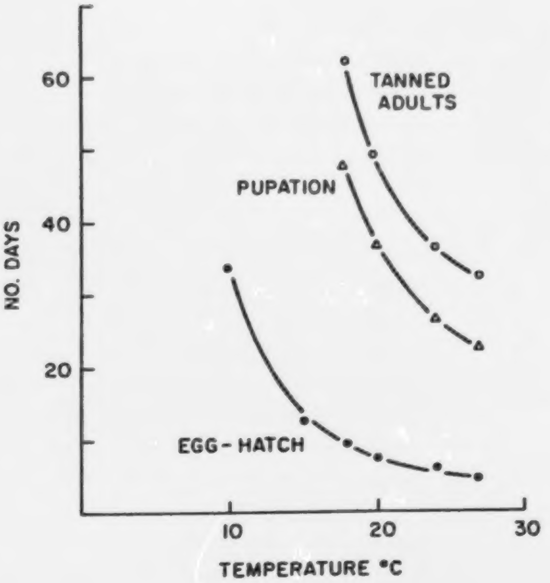

Figure 1 - Relationships between developmental times for various stages of the mountain pine beetle and rearing temperature (after Safranyik and Whitney 1985).

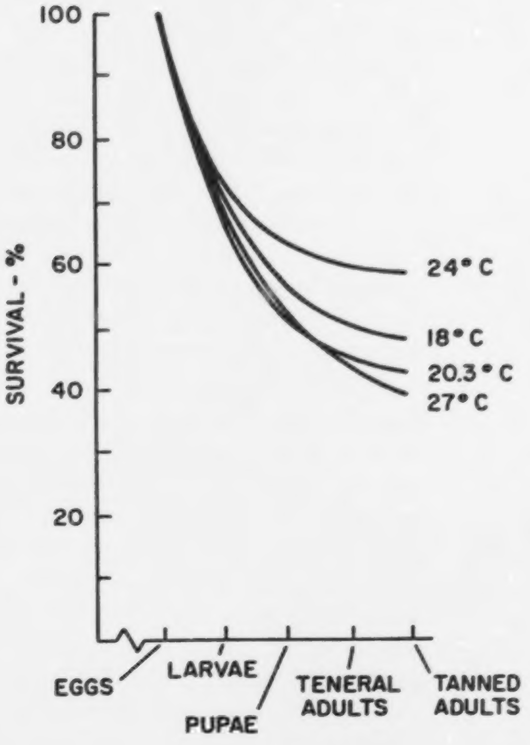

Figure 2 - Relationships between percent survival and rearing temperature for various developmental stages of the mountain pine beetle (based on Safranyik and Whitney 1985).

Survival of all stages of MPB is reduced by unseasonably cold weather and very high summer temperatures. Eggs are least freeze tolerant followed by pupae, adults and larvae (Safranyik *et al*. 1974). The lethal low temperature threshold for eggs is near -18°C and for larvae it is between -34 and -38°C (Wygant 1940, Somme 1964). Cold-hardiness of larvae generally increases upon exposure to freezing temperatures; thus, cold hardiness is greatest from mid-to late winter. Prolonged exposure to high temperatures near 38°C will cause death of all brood stages but with short exposure the lethal high temperature is above 43°C (Patterson 1930). High temperatures of this magnitude rarely occur in British Columbia.

The effects of temperature on brood establishment, development and survival are modified by the insulating properties of the bark; also, winter kill of MPB will generally be inversely related to tree diameter, as greater amounts of heat are stored in large diameter trees (Wygant 1940). In addition, brood mortality from desiccation is generally less in larger diameter trees compared to small diameter trees, probably because of the inverse relationship between sapwood thickness and diameter for trees of the same age (Amman 1978).

Variations in Life Cycle

Differences in climates of different regions within the distributional range of MPB and the varying local weather conditions cause considerable variation in the onset and duration of the emergence and flight periods and the length of the life cycle in place and time.

Typically, in the optimum range of its geographical distribution, the peak flight and attack of MPB is in the period from late July to mid-August and a 1-year life cycle is normal. However, even in the optimum range the median emergence time following exceptionally warm weather during the development period can occur as much as one month earlier than following abnormally cool weather. In most years, however, the median dates for the onset of peak emergence will differ by less than 10 days: peak emergence normally lasts from 7 to 10 days, but can vary from 3-4 days to three weeks. Cool, rainy weather will extend the periods of emergence and flight. New adults, especially those that matured, emerged and attacked early in a warm year, may re-emerge later in the season and infest a second tree (Reid 1962a). In some years, progeny resulting from this second flight may constitute the bulk of the next generation of beetles when progeny from the first attack suffers heavy mortality in lodgepole pine due to drying of the bark (Reid 1963). Usually, however, only a small proportion of females make second attacks and if the second attack occurs late in the season, the eggs and young larvae suffer heavy winter mortality. Therefore, it appears that in most years survival of MPB progeny resulting from the second attack will be low and supplement larger surviving populations from the earlier flight. A high proportion of parent beetles may survive mild winters. Some of these beetles may emerge prior to the emergence of their progeny (Amman and Cole 1983), usually during late May through early June in B. C. Usually, these beetles will construct egg galleries in the green phloem of trees that were strip-attacked, resistant, or trees that were successfully attacked late in the season the previous year (Rasmussen 1974). Amman and Cole (1983) feel that most parents that survive the winter tend to emerge at the same time as their progeny.

In cooler environments, such as at high elevations and near the northern edges of the distributional range of MPB, the most frequent deviation from the typical flight and attack period occurs when all or part of the broods take longer than one year to mature and initiate attacks (i.e., when all or part of the broods overwinter twice in their brood trees). In these situations, there will be one or two peaks in attack and flight activity: one peak can occur in the period from late May to mid-June and the other during mid- to late summer. The result is an overlapping of generations that may persist for several years or may even become the norm in some areas. However, there is insufficient information regarding flight and attack periods in situations when the beetle has an extended life cycle. Generally, the earlier peak in the seasonal flight and attack results mainly from the spring emergence of brood adults that matured during the previous season (but could not emerge due to cool temperatures) and the later peak from broods that overwintered in the immature stages, usually as half- and full-grown larvae.

During years when attack occurs late in the season, gallery elongation and egg laying are frequently not completed before the onset of cold weather. Those surviving females that established egg galleries at the end of the previous season break dormancy and may continue gallery elongation and egg laying during late spring next year. Egg gallery elongation resumes with cutting of a hole through the bark at the top of the old gallery for the purpose of draining pitch and clearing frass from the new gallery. Thus, new pitch tubes occur on the trees, usually in early June, and the impression is created that these trees were newly attacked. Also, young adults that overwintered in their brood trees tend to attack previously infested trees if these have green phloem. Therefore, in situations when MPB has a partial 2-year cycle, the late spring emergence and flight may not always result in a large increase in newly attacked trees.

The extended life cycle can make yearly assessments of beetle population size and damage trend, based on tree crown symptoms alone, very unreliable. For example, during years when a significant proportion of the trees are attacked in late summer and late spring of the following year the crowns of many of the attacked trees of both types will likely fade during the same time period, usually in late summer or early fall, depending on summer temperatures.

Effects of Climate and Weather on Population and Damage Trends

Generally, in the optimum geographic range of MPB (in areas where the beetles have a predominantly 1-year cycle) the frequency of adverse weather conditions is not great enough to prevent development of outbreaks or to reduce populations to endemic levels. Although in some years adverse weather can cause a decline in population and damage levels and, in some cases, the collapse of infestations; more usually, reversals in population and damage levels will be temporary and the course of outbreaks is determined by factors other than climate.

On the other hand, at high elevations and near the northern limits of the beetle's range, climate becomes a dominant factor affecting both the distribution and abundance of MPB (Safranyik 1978). In these habitats, beetle development tends to be out of phase with the cold season and length of the life cycle increases, resulting in decreased survival. As a consequence, epidemics tend to be less frequent and intense in these areas. However, outbreaks are persistent and may continue just as long as in areas with more favourable climate.

An example of the effects of regional climate on the rates of increase in damage and population levels is given in Figure 3. Yearly, from 1972 to 1984 inclusive, total numbers of trees killd by MPB in the 6 forest regions of B. C. were estimated by the Forest Insect and Disease Survey (FIDS) of the Canadian Forestry Service. Preliminary analysis indicated that the average yearly rate of increase in the number of trees killed by MPB was as follows: province-wide = 1.99; Nelson Region (milder climate) = 2.18; the Prince Rupert Region (colder climate) 1.52. Although numerical differences in these rates are not great, their

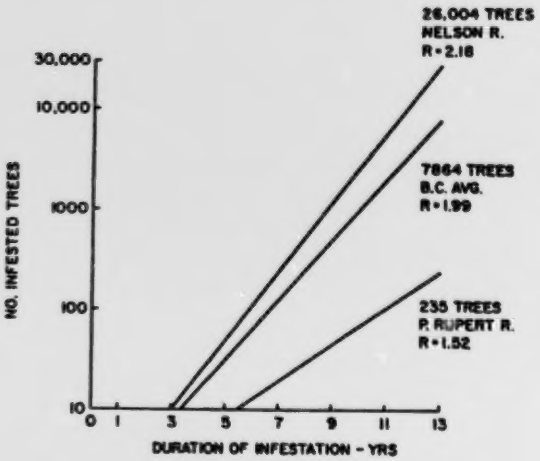

Figure 3 - Comparison of yearly mortality from mountain pine beetle for a 13 year period in the Nelson and Prince Rupert Regions and for British Columbia. Graphs are based on estimated yearly rates of tree mortality (R-values on the graphs) from FIDS surveys and an initial value of one attacked tree in year 1 (1972) of the infestation.

cumulative effects, in terms of number of trees killed over a period of years, can be startling. For example, starting in 1972 with one infested tree each in the Nelson and the Prince Rupert Region, at the rates of increase given above, the number of killed trees in the 13th year of the infestations would be 26,004 in Nelson and 235 in Prince Rupert, and the corresponding cumulative numbers of trees killed over the 13-year period would be 47,931 and 683.

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EFFECT OF LIFE CYCLE DURATION ON FACTORS LIMITING SURVIVAL OF THE MOUNTAIN PINE BEETLE

Richard F. Schmitz[1]

Introduction

In the western United States, the mountain pine beetle (MPB), *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae), causes most severe tree killing of lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann, growing in stands with significant numbers of trees 80 years or older that are greater than 20 cm in diameter at breast height (dbh). Trees with these characteristics produce the greatest number of beetles per unit area of bark. Equally important, the stands must be growing in locations where temperatures are optimum for beetle development so that development is synchronized with seasonal changes in weather patterns (Amman *et al*. 1977; Safranyik *et al*. 1974). In general, survival is best in locations where temperatures are such that the beetle completes development in 1 year (Amman 1973; Safranyik 1978). When the duration of the life cycle extends beyond a year, the prolonged exposure of developing broods to certain mortality factors further reduces survival from that recorded after the first season.

This paper reviews the relative importance of mortality factors known to affect survival of MPB populations at a site in northeastern Utah where the beetle completes development within a year. In addition, major mortality factors affecting populations with 2-year life cycles occurring along an elevational transect in northwestern Wyoming are identified and compared with those determined for populations completing development within a year.

Life Cycle Duration

The effect of weather and climate on the seasonal history and development of the beetle has been summarized for a number of locations in the western United States and Canada (Safranyik *et al*. 1974; Safranyik 1976; Amman 1973; Amman and Cole 1983; Amman, these proceedings). These findings show the usual 1-year life cycle occurs at elevations below 2,440 m. In infestations at these elevations, new adults emerge in mid-July or early August, with egg hatch following within a week of oviposition. The majority of the ensuing larvae reach the third and fourth stages prior to the onset of cold weather in

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October and November. The larvae remain dormant until warmer temperatures in April allow them to resume feeding until larval development is completed in June. The larvae pupate and transform to adults during late June to mid-July.

At higher elevations, the beetle often requires more than a year to complete a generation. For example, in northwestern Wyoming, measures of rate of development along with elevational transect revealed the beetle had a 1-year life cycle at 1920 and 2,130 m. At 2,450 m, part of the population completed development within a year, but the remainder required a second summer to complete a generation. At elevations between 2,580 and 2,750 m, most beetles required 2 years to complete a generation (Amman 1973). In Canada, Reid (1962) found the MPB usually had one generation per year in Invermere, British Columbia, while in 1956 in Banff National Park, Alberta, beetles required 2 years to complete a generation. Therefore, the duration of the beetle varies from 1 to 2 years because of elevation and latitude or variation in weather from year to year.

The key to life cycle duration appears to be the temperatures during the flight and oviposition periods in August and September. Cool temperatures or rainy weather delay flight, oviposition, and early larval development, so that a large percentage of the brood enters the winter as eggs and first and second stage larvae (Amman 1973; Safranyik 1978). Brood that survive the winter in these stages are usually unable to complete development within a year. Developmental rates of the four life stages, and thereby the duration of the life cycle, are governed by heat accumulation in terms of degree days above a stated temperature threshold (a degree day is 1 degree above the temperature threshold for 24 hours). Powell (1967) found development from egg to new adult required 348 degree days above 10°C, as measured in the bole of the tree. A second year is required to complete a generation when heat accumulations fail to reach this threshold during the first year of development.

Evaluation of Mortality Factors

To be an effective mortality factor, Amman and Cole (1983) suggested the factor should cause a departure from expected survival and emergence as predicted from phloem thickness. An effective mortality factor would then lessen the total number of trees killed or slow the expected rate of tree killing.

To evaluate the relative effectiveness of mortality factors common to MPB, life table samples were taken for 13 years from MPB populations in Montana, Idaho, Utah, and Wyoming (Cole 1974, 1975; Amman and Cole 1983; Amman 1984).

Effectiveness of the mortality factors were measured on two 230 cm^2 samples removed within 30.5 cm of the 1.4, 3.7, and 6.1 m levels from the same trees at four times - October, May, later June, and late July to early August (Carlson and Cole 1965). Trees were stratified by diameter classes: 23 cm dbh and less (trees 30.2 cm dbh); 30.5 cm dbh (trees 30.5 to 37.9 cm dbh); and 38.1 cm dbh and greater. The number of attacks, total length of egg gallery, all stages of the MPB, and associated insects were counted.

Initial MPB densities were established by determining the number of live MPB stages and dead adults in the first (October) sample. Dead stages were assigned to 11 sources of mortality, as follows:

1. *Within competition*: Mortality was attributed to this factor when two larval mines from the same egg gallery coalesced and only one larva was present, or one of the two larvae was partially consumed.

2. *Between competition*: Mortality attributed to this factor had the same appearance as the within competition, except the larvae involved were from mines from adjacent egg galleries.

3. *Clerids*: Larvae of two species, *Thanasimus undatulus* Say and *Enoclerus sphegeus* F. (Coleoptera: Cleridae), were the most common; additionally, tunnels were present, filled with characteristic bits of phloem left by the larvae as they chew to enlarge MPB larval mines in search of the larva or pupae at the end of the mine.

4. *Coeloides*: Parasitism by *Coeloides rufovariegatus* (Provancher) (Hymenoptera: Braconidae) was identified by its characteristic larval form or cocoon at the end of a larval mine.

5. *Medetera*: The area surrounding larvae killed by the predacious fly *Medetera aldrichii* Wheeler (Diptera: Dolochopodidae) was surrounded by a characteristic staining likely caused by fungi developing on the MPB remains.

6. *Pathogens*: Larvae killed by pathogens had normal colour but were

flaccid or less active. In the latter stages of infection, the larvae were often covered with the fungi.

7. Woodpeckers: Predation by woodpeckers, *Picoides tridactylus* (L.) and *P. villosus* (L.), was identified by the holes pecked through the bark above larval mines. When bark was chipped off the tree, the number of MPB brood destroyed was estimated by determining the larval densities nearby and noting the area of bark removed.

8. Temperature: Larvae killed by sub-freezing temperatures can be identified by their black colour. The approximate time of death was determined by the degree to which the body had dried and shriveled. If larvae were soft and only partially black, death likely occurred within weeks.

9. Drying of the Phloem: Larvae thought to be dead from drying of the bark were often shriveled and cream-coloured rather than black like those killed by cold temperatures.

10. Pitch: Larvae killed by pitch were found in areas of the bark characterized by particularly tacky accumulations of pitch.

11. Unknown: Dead larvae for which there was no apparent cause of mortality were listed as unknowns.

Major Factors - 1-Year Cycle

Figure 1 shows the relative importance of the mortality factors studied, based on their probability of causing the death of mountain pine beetle brood that complete development within 1 year. The data used to develop these relationships were recorded in an infestation in the Wasatch National Forest in northwestern Utah (Amman and Cole 1983). The infestation level was classified as "high endemic," based on annual tree mortality and beetle survival rates during the 9 years of the study. Analysis of the data revealed that cold winter temperatures and drying of the phloem were the two major causes of mountain pine beetle brood mortality. The results were typical of those observed elsewhere (Cole 1981). The greatest effect of these two agents was on beetles infesting small diameter trees; the least was in large diameter trees. The effect cooler temperatures at the higher elevations have on MPB emergence, and ultimately survival, is shown in Figures 2 and 3. The cooler temperatures delay peak emergence as much as 21 days over that observed

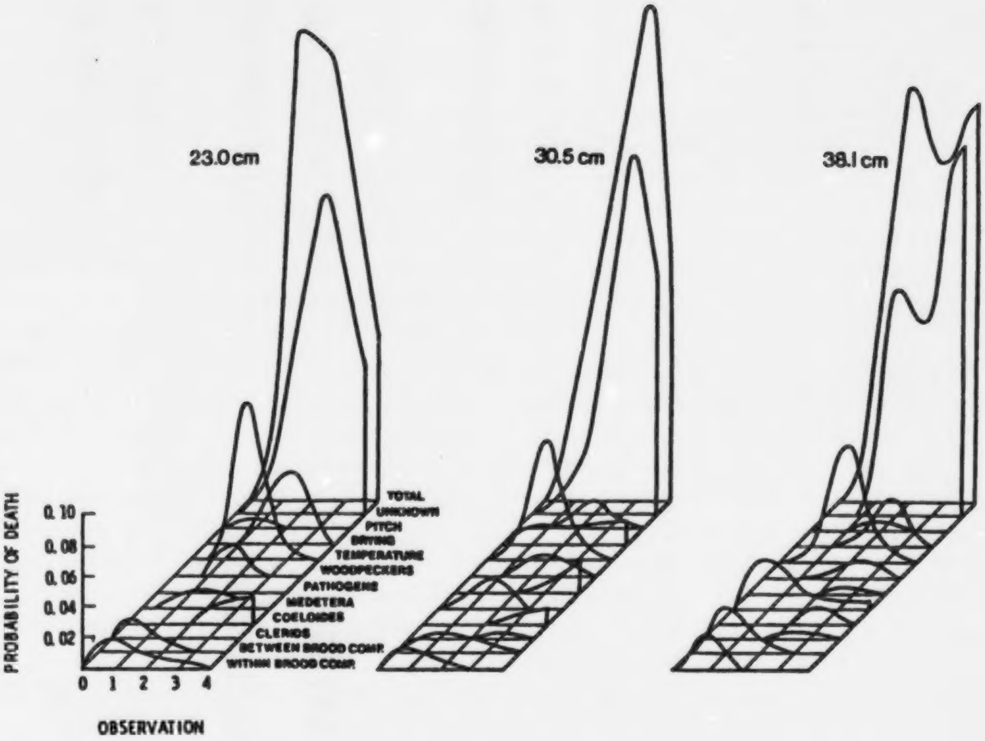

Figure 1. Probability of mountain pine beetle death from specific factors in three diameter classes, Logan Canyon, Wasatch National Forest, Utah, 1971 - 1980.

at 2,440 m. Additionally, the slower rate of development at the higher elevations results in a high percentage of eggs comprising the pre-winter population (Figure 3). The greater the percentage of eggs in the pre-winter population, the more likely the brood will suffer a proportionally high mortality from winter temperatures.

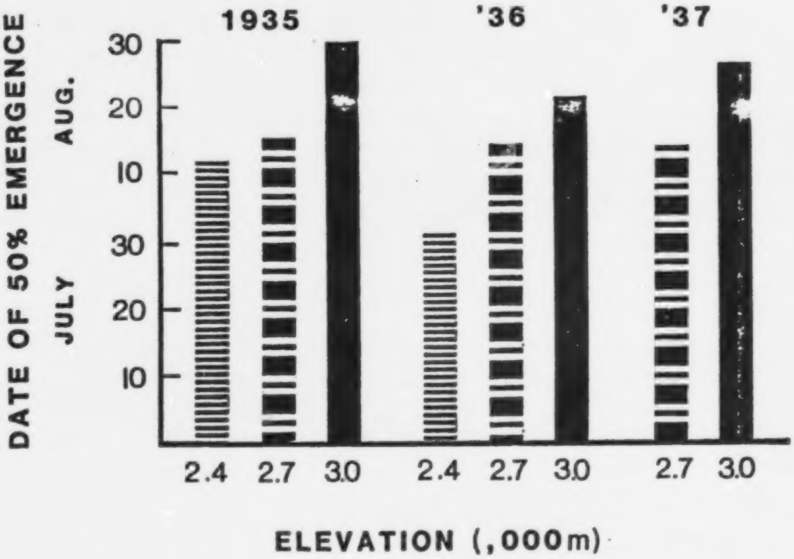

Figure 2. Effect of elevation on the rate of MPB emergence, Medicine Bow National Forests, Wyoming, 1935 - 37. After DeLeon (1940).

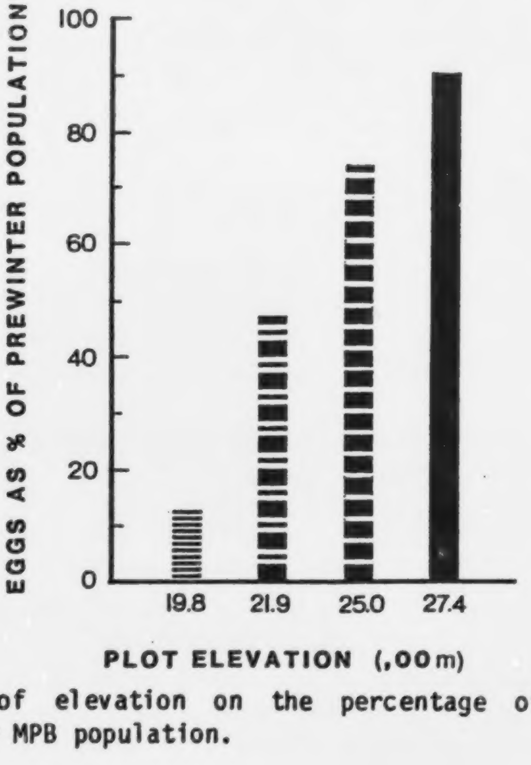

Figure 3. Effect of elevation on the percentage of eggs in the prewinter MPB population.

With the exception of the predacious fly, Medetera, the probabilities of death resulting from parasites, predators, pathogens, and pitch was notably less then those recorded for temperature or drying, regardless of tree size. Data from the 38.1 cm diameter class showed that the probability of death from Medetera was slightly greater than that from drying but less than that from cold temperature.

Comparison of the mortality caused by predators and parasites revealed the probability of death from clerid larvae was least, from Medetera was the greatest, and from Coeloides, intermediate to the two. Parasitism by Coeloides was greatest in the smallest diameter class and least in the largest, while predation by Medetera larvae was greatest in the largest diameter class and least in the smallest diameter class.

The probability of death caused by woodpeckers was greatest in the 23 cm and 30.5 cm classes, as were losses to pathogens and pitch. Increased resinosis in these two classes is likely due to the low attack densities sustained by trees in these diameter classes.

Results obtained from study of mountain pine beetle populations with a 1-year life cycle at the Logan Canyon site substantiate findings of earlier life table analyses conducted elsewhere (Cole 1981). Overall, the findings suggest that none of the natural control factors acting in the presence of others are effective in suppressing MPB populations below acceptable levels. The Logan Canyon population maintained a high endemic level for 9 years, with little changes in the abundance or effectiveness of natural controls. The population has only recently begun to decline because the large diameter trees that provide for optimum brood survival have been killed.

Major Factors - 2-Year Cycle

Comparison of the number of MPB killed per sample by selected mortality agents along an elevation transect in northwestern Wyoming revealed that cold temperatures, predators and parasites, and woodpeckers were the most effective agents (Table 1). In general, the effect of cold temperature tended to increase with increasing elevation with the exception of the site at 2,130 m. The severe losses to cold temperature at this elevation are attributable to lower than usual maximum temperatures during August and September 1968. This delayed adult emergence so that much of the brood entered winter as eggs and first stage larvae, which are especially susceptible to cold winter temperatures.

Table 1. - Effect of elevation on life cycle duration and mortality by selected agents, northwest Wyoming, 1967 to 1969

Mortality Agent	Number of MPB killed per m^2			
	1 Year		Transition	2 Year
	1920 m	2130 m	2450 m	2750 m
Predators and parasitoids	30.1	36.6	10.8	34.4
Temperature	7.5		15.1	74.3
Woodpeckers	2.2	8.6	8.6	8.6
Within competition	2.2	<0.1	<0.1	<0.1
Between competition	2.2	<0.1	<0.1	<0.1
Pathogens	0.2	<0.1	<0.1	<0.1
Drying of phloem	<0.1	<0.1	<0.1	4.3

Mortality resulting from predator and parasites was rather constant for the three life cycle durations, except that in the "transition" where both 1-year and 2-year MPB life cycles are evident. Under these conditions, many MPB larvae may be smaller than those normally preferred by the parasite Coeloides rufovariegatus, thereby reducing its effectiveness.

Woodpeckers took 54 percent of the parent adults at 2,580 to 2750 m, 37 percent at 2,450 m, and 27 percent at 2,130 m. Woodpecker predation was not determined at the 1,920 m site, but 67 percent parent adults survived, and woodpeckers likely took only a small number of parents at this site. Additionally, they may have taken fewer parents at the lower elevation because larvae at this elevation were more numerous and larger (Amman 1973). Conversely, at the higher elevations MPB larvae were generally smaller, accounting for the preference for parent adults (Koplin and Baldwin 1970). Despite this preference for parent beetles, other brood stages are dislodged as woodpeckers search for suitable prey. Removal of patches of outer bark speeds drying of the phloem, often causing dessication of adjacent brood, and further reducing survival. Such mortality is often difficult to assess (Moeck and Safranyik 1984; Otvos 1979).

Competition for phloem was greatest at the lowest elevation because larvae were more numerous in contrast to the higher elevations, where most of the mortality to early stage larvae occurred during the winter. Consequently, larval competition did not occur.

Overall MPB survival declines sharply when the duration of the life cycle exceeds 1 year (Table 2). There was much less difference in survival between broods requiring 2 years to complete a generation and those at the "transition site" where the beetle undergoes both 1-year and 2-year cycles, depending on micro-environmental factors such as the aspect of the tree infested. The difference in survival rates between 1-year and 2-year cycles was due almost entirely to the effects of cool temperatures that delay development so that a large percentage of the developing larvae fail to reach the third and four stages, and hence, are especially susceptible to winter temperature.

Table 2 - Survival of the MPB in relation to duration of life cycle, northwest Wyoming, 1967 to 1969

	1 Year		Transition	2 Year
	1920 m	2130 m	2450 m	2750 m
Generation survival (%)	17.6	2.6	7.4	4.0
Emerging adults	36.0	5.0	6.0	6.0
Percent change	+172	-411	-326	-372

Conclusions

Data amassed to date suggest that cool temperatures that retard MPB emergence and oviposition result in poor synchrony of the beetle life cycle with subsequent weather conditions. This results in life cycle durations that exceed 1 year and reduced survival, particularly at high elevations. In general, the mortality factors that are most important during the 1-year life cycle cause similar levels of mortality when more than 1 year is required to complete a generation.

Because survival and emergence are reduced at the higher elevations, fewer trees are killed at these elevations than at low elevations. For example, Amman and Baker (1972) found that 75 percent of the trees 23 cm dbh and larger survived MPB infestation at 2,670 m elevation on the northwestern Wyoming transect. Only 37 percent survived at 2,060 m near the base of the transect. Therefore, phloem thickness that regulates MPB populations at lower elevations is not a limiting factor at higher elevations. At the higher sites and northern latitudes, cool temperatures that delay brood development and increase losses to winter temperatures replace food as the factor limiting population survival.

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DYNAMICS OF 1-YEAR AND 2-YEAR LIFE CYCLE POPULATIONS OF MOUTAIN PINE BEETLE AND RELATED TREE LOSSES

Gene D. Amman[1]

Introduction

The dynamics of mountain pine beetle (MPB) populations are closely tied to variations in their life cycle. Generally, beetle populations that have a 1-year life cycle are regulated by their food supply - - that is, lodgepole pine with large diameter and thick phloem. But beetle populations that have a 2-year life cycle, and those having both 1-year and 2-year cycles, are regulated by weather.

Life Cycles

Variations in the length of the life cycle set the stage for dynamics of MPB populations. Three situations exist:

1. Day-degree (a day-degree is 1 degree of temperature sustained for 1 day above the threshold temperature of development) accumulation is adequate for development to be completed consistently by late July and early August (1-year cycle).

2. Day-degree accumulation is inadequate for development to be completed in 1 year. The cycle usually is completed in late July and August of the second year (2-year cycle).

3. The transition zone between situations 1 and 2 (both 1-year and 2-year cycles).

Situation 1. Typically, at low elevations, the life cycle begins the last week of July and first week of August when new adult beetles emerge and attack green trees, constructing their galleries and laying eggs. Most of these eggs will hatch before the cold temperatures in late October and early November prevent additional egg hatch and larval development. Conditions are usually best for MPB when attacks by parent beetles occur in late July and early August and galleries average about 25 cm long. Under these conditions, most eggs will hatch and many larvae will reach second and third stages before cold temperatures set in and prevent further development. The larger the larvae - - that is, the later stages - - the less likely they will be killed by sub-freezing temperatures during the winter (Amman 1973; Reid 1962; Safranyik 1978). The estimated minimum day degrees needed for MPB to complete its life cycle in a single year is 833 (Safranyik 1978).

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In areas where the 1-year cycle prevails, foliage of trees is bright orange within 1 year after trees are killed by MPB.

Situation 2. In Situation 2, weather usually is too cool for MPB to complete a generation in 1 year. This usually occurs at high elevations; the elevational level gets progressively lower as latitude increases (Safranyik *et al*. 1975). Adult beetles emerge and infest trees about the same time as those undergoing a 1-year life cycle, that is, late July and early August. However, cooler temperatures in these areas slow gallery construction and oviposition. Eggs take considerably longer to hatch. Eggs hatch after 10 days at a constant 20°C, compared to 37 days at a constant 10° C.

First and second stage larvae can feed and develop at temperatures as low as 2.2°C (McCmabridge 1974). However, by the times the eggs hatch, not enough day degrees above the developmental threshold temperature remain before winter for development to proceed to third and fourth stage larvae, which are most resistant to freezing. Higher threshold temperatures are required for development to proceed to later stages. For example, fourth stage larvae require temperatures higher than 10°C in order to pupate.

In Situation 2, many eggs fail to hatch and are killed by sub-freezing temperatures during the winter. Larvae usually enter the winter in first and second instars, which are less cold hardy than the larger third and fourth stage larvae. A high percentage of these larvae succumb to sub-freezing temperatures. Development of surviving larvae begins in the spring and continues until fall. At this time, beetles can be found as large larvae, pupae, callow adults, and a few mature adults. These enter the winter, and usually all pupae, a portion of the callow adults, and most of the mature adults are killed by sub-freezing temperatures the second winter of the 2-year cycle (Amman 1973; Reid 1962; Safranyik 1978). Those that survive will complete development and emerge to infest trees in July and August, thus completing their 2-year cycle. Mortality due to all causes can be high during the 2 years.

Timing of the life cycle is critical where the 2-year cycle occurs, and MPB are literally at the mercy of the weather. Either a slight delay or a slight speed-up of the life cycle due to local temperatures can place the beetles in jeopardy. When timing is perfect for beetle survival, beetle production from the 2-year cycle can be high.

In areas where the 2-year cycle prevails, foliage of infested trees usually is light green with a few orange needles 1 year after beetle attack.

Situation 3: The third situation occurs in transition zones between low and high elevations. In these transition zones, both 1-year and 2-year life cycles are represented, frequently within the same infested tree. The difference sometimes occurs simply because a portion of a tree trunk receives more direct sunlight, thus more day degrees above the threshold of beetle development, and consequently, more rapid beetle development.

In these transition zones, eggs laid early will hatch, and development and emergence will generally follow those of 1-year cycle beetles at lower elevations. Eggs laid late will hatch late, if at all, and will generally follow development and emergence of a 2-year cycle beetles. Any unhatched eggs in the fall are killed by cold winter temperatures. Often, beetles in the transition zone will develop to pupal, teneral adult, and adult stages during the first full summer. These stages enter the winter and are highly susceptible to winterkill (Amman 1973; Reid 1962; Safranyik 1978). Thus overall, heavy mortality among this cohort frequently occurs.

It is important to remember that local weather dictates these cycles and makes precise predictions difficult, if not impossible. For example, a series of warm seasons results in the typical 1-year cycle extending to higher elevations. Warmer than average seasons will result in increased beetle survival and, consequently, increased tree mortality. Cooler than average weather during beetle emergence and attack or during brood development can cause a shrinking of the beetle's range to areas of favourable weather (Safranyik 1978).

Host Tree

Although length of cycle sets the stage for dynamics of MPB populations, host tree dimensions play a dominant role, particularly in areas where optimal conditions prevail for the 1-year life cycle.

MPB-Host Tree Interactions - Phloem, the food of developing MPB larvae, regulates dynamics of mountain pine beetle in areas optimum for the 1-year beetle cycle. Beetle production is directly related to phloem thickness when egg gallery density is high and adequate moisture for beetle development is available throughout the life cycle. Low density of egg galleries will result in low phloem use, and beetle production will be directly related to gallery density (Amman 1972).

At very low densities of attacks and egg galleries, and when the rate of attack is low, beetles will be pitched out or galleries inundated by pitch, resulting in no beetle production and the tree not being killed. Even if the tree is killed, beetle brood may not be produced because of resin in the bark and galleries. The interactions of attacking MPB, blue stain fungi introduced into the tree by MPB, and the host tree have been described (Reid *et al.* 1967; Safranyik *et al.* 1975; Shrimpton 1978).

In some cases, phloem may be thick enough for high brood production, but moisture levels in the host tree may fall below that required by the developing beetles, particularly in lodgepole pine harbouring MPB having a 2-year cycle.

Both phloem thickness and moisture level are related to diameter of lodgepole pine (Amman 1978). Consequently, a fairly high correlation exists between diameter and brood production in populations having a 1-year cycle. The close association of beetle production to diameter of lodgepole pine suggests why MPB show such a strong preference for large trees during an outbreak.

The exact mechanism MPB use to select large trees has not been identified. Sight was suggested by Shepherd (1966), whereas Safranyik *et al.* (1975) suggested random selection involving the greater surface area of large trees. Another possibility is olfaction, whereby MPB detect the greater terpene quantities found in phloem of large rather than small diameter trees and in thick rather than thin phloem (Cole *et al.* 1981).

Life Cycle-Tree Loss Interactions - Not surprisingly, tree losses are related to the life cycle of MPB. When beetle populations build to epidemic proportions, tree losses are heavy where the 1-year life cycle prevails. Losses generally are progressively less as elevation and latitude increase, simply because beetle survival declines as the beetles infest trees where part of the population completes the life cycle in 1 year and the remainder requires 2 years. Least tree loss usually will occur where the life cycle requires 2 years. As an example, on the north slope of the Uinta Mountains in northern Utah during a large MPB infestation from 1955 to 1963, losses of lodgepole pine 22.9 cm diameter at breast height (dbh) and larger were 36.5 percent at 2,650 m elevation, but only 1 percent at 3,050 m or greater. The lowest elevation for lodgepole pine is about 2,590 m in this area. Losses in northwestern Wyoming showed tree losses similar to those in northern Utah when adjusted for latitude (Amman _et_ _al._ 1973). In northwestern Wyoming, losses of trees ranged from 33 percent at 2,440 m elevation to 10 percent at 2,835 m (Amman and Baker 1972).

During periods of several years when temperatures are warmer than average, 1-year life cyles become more prevalent in the transition zone between 1-year and 2-year cycle beetles, permitting greater beetle survival and hence greater tree losses. An example is whitebark pine losses between 2,740 and 3,050 m elevation in northwestern Wyoming (Baker _et_ _al._ 1971): 20 percent of the trees were killed and then the infestation died even though potential for infestation continued to be great because of the large diameter trees with thick phloem. Trees killed the last year of the infestation revealed many beetle pupal chambers but no emergence, thus suggesting the beetle cycle was extended because of cool weather. Beetles entered winter in stages very susceptible to winterkill, and most of the population was killed.

Another aspect of MPB dynamics is beetle emigration. Dynamics of local populations can be greatly altered by emigration of large numbers of beetles from nearby stands, especially those at lower elevations. Beetle populations are more likely to build up at low elevations, and many more beetles emigrate to higher elevations than vice versa. The emigration of large numbers of beetles increases the amount of mortality above what would normally be expected from resident populations at mid to high elevations. Some areas might never have an infestation if it were not for emigrating beetles that increase the resident population, thus making an outbreak possible.

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QUESTIONS

QUESTION: How long must larvae in a tree be exposed to below zero temperatures before they die?

LES SAFRANYIK: The super cooling temperature at which the instantaneous death of mountain pine beetle larvae occurs is about minus 36 degrees centigrade. This causes a wave of ice crystal formation; in other words, it turns into instant ice. From this process the disruption in the cells is so great that the insect dies.

There is a considerable difference, however, between air temperatures (ambient temperatures) of minus 40 or even minus 45, as opposed to temperature conditions under the bark. Bark happens to be an excellent insulator. For instance, under lodgepole pine bark just one half centimeter thick, if you drop the temperature at 2 degrees centigrade per hour from about 0 degrees to about minus 30, the under-bark temperature follows the air temperature with a time lag of two to four hours. When temperature charts show a low of minus 40 degrees, that temperature may only be maintained for only a few minutes, and then the temperature recovers. What this means in terms of under-bark temperatures, is that you never got near lethal temperatures under the bark.

QUESTION: Would the panel address what overwintering cold temperature mortality really means in terms of population dynamics?

GENE AMMAN: In our area we consistently lose 50% of the population to winter temperatures, and I don't think it means very much to the dynamics of the beetle. It seems that where significant mortality comes in due to temperature, is in the early spring, after the larvae have started to feed, and then they seem to be very susceptible to freezing temperatures that don't have to be particularly low to kill those larvae. I think that's where we get some fairly significant mortality. It takes very heavy mortality to be significant in the dynamics of the beetle. What frequently happens is you get cold temperature in a portion of the infestation - say on the mid-slope - it tends to be a little bit warmer, so you get fairly good survival there, or in very low areas you get a lot of mortality but on slight rises you can get pretty good survival, so the population can recover from that type of mortality.

LES SAFRANYIK: Just two points, one is how you assess winter mortality. Larvae typically go into dormancy, especially in the mid-winter period. Larvae collected in mid-winter (January/February) and kept at room temperature for 2 days may appear to be dead; however, this may not really be the case. When larvae go into dormancy, it requires a considerable amount of heat input before they come out of that state. So it's quite important when you assess winter mortality, to keep bolts or slabs of larvae at room temperatures for at least three days, and possibly four days before you assess survival, or conversely, mortality.

The other point is that we're preoccupied too much with assessing mortality in terms of percentages. I can illustrate this to you very simply. One percent survival of 100 million beetles is still a million beetles. It's a heck of a lot of beetles and the population will recover in no time. Survival should be assessed in terms of the population density of the beetles that are surviving. In other words, on average, a mountain pine beetle lays, say, 60 eggs. Even if two of those eggs survive, you can still produce a surplus number of beetles and the population could still increase. The basic difference between an epidemic stage and an endemic stage population is one or two percentage difference in survival from the egg to the mature adult stage.

QUESTION: You've spoken about mortality of the larvae in the tree. Are there any other stages when the beetles are particularly vulnerable?

LES SAFRANYIK: Yes, it is in relation to the heat unit requirements for pupation. Both Gene's group and ours found that for the mature larvae to turn into pupae you have to maintain temperatures of 10 degrees in the case of the situation in the United States, further south, and in our case, 15 degrees or greater. Otherwise, the mature larvae won't pupate. In other words, there can be a mechanism there to prevent the brood to grow into a non-cold-hardy state before the winter, such as pupae or young adults.

QUESTION: I wonder if the panel would like to address the dispersal phase?

LES SAFRANYIK: That phase of the biology of any insect is rather difficult to investigate. As related to mountain pine beetle, there is quite a bit of circumstantial evidence as well as some experimental evidence relating to dispersal. The circumstantial evidence comes from observations such as collections of mountain pine beetle at high passes on the snow line as far as 20-30 miles away from the nearest forested area. As well as situations such as occurred recently in the Cypress Hills, an area between Alberta and Saskatchewan. There are large stands of lodgepole pine and, as far as we knew up to the late '70's, it was free of mountain pine beetle infestation. No mountain pine beetle had ever been collected from this area, and the distance between that area and northwestern British Columbia and the northern Montana/Idaho region where very large infestations existed, would be something like 150-200 miles. All of a sudden, pockets of infestation showed up in these stands. Initial reactions were that perhaps beetles were introduced through transportation of infested logs to the east from the foothills or transportation of firewood. However, I think studies indicate that the infestation most likely originated from long distance dispersal of these beetles from the southwestern corner of British Columbia and the northern Montana and Idaho regions. Indeed, when we looked at the direction of prevailing winds etc., they all pointed in that direction.

JOHN BORDEN: We have been working in the Quesnel and the Merritt Districts trying to eradicate small infestations. Our attempts at using semiochemicals and herbicides (arsenicals) have not been successful in single pass treatments, but one thing that is interesting is the check spots. We've had 20 of them in the last two years, and we were simply assessing the emergence from them and the attack in a 50 m wide band around those spots. In six of the 20 spots, there wasn't a single green attacked tree within that 50 m band around those spots, and in more than half of them, the green to red ratio was less than one. That means that the beetles in many spots are getting up and leaving the area. Therefore, if you don't treat a spot infestation immediately, there is a considerable chance that the beetles are going to emerge in a dispersal mode, and end up who knows where, which will certainly create further problems down the road.

DICK SCHMITZ: In the thirties, some of the people out of the Coeur D'Alene Lab were looking at the mountain pine beetle and lodgepole in the Big Hole country and had the brain storm that if they cut a swath about a mile wide they could break up this eastward movement of the insect. Fortunately, someone thought maybe we ought to get up in the air and see where these beetles really are. I recall they flew in planes and put nets on these planes, and at 14,000 - 18,000 feet, they were catching mountain pine beetle in these nets. They're very obviously at an elevation where they can move some great distances rather passively.

QUESTION: As I understand it, the long term management plan for areas like the Bulkley TSA is to create a mosaic of ages of the stands. If that is achieved, will there still be the same danger of catastrophic losses from pine beetle?

GENE AMMAN: I think that would reduce it considerably. Then you don't have so much acreage of susceptible size and age category at any one time, and should be able to deal with it quite effectively.

QUESTION: In the Prince George Forest Region this year, we've found that the 1984 beetle flight was quite late in the year, late August last year, and consequently, we're finding a lot of egg galleries with just a female in it, or if there is a pair of beetles, there are no eggs present, and virtually no larvae. Has there been a case where parent adults could overwinter, and then resume mating and egg laying the following year?

LES SAFRANYIK: In the late seventies and early eighties, I observed it. When these parent females survive, they tend to come out of dormancy, and, if the tree is still suitable, they'll just bore a hole to the outside for draining pitch out of the new section of the gallery they construct, and they'll just keep on going, elongating the old gallery and laying more eggs. They don't need to mate again to lay viable eggs.

GENE AMMAN: I've seen the same sort of thing at high elevations down in our area. Just an extension of the gallery in the spring if the phloem remains fairly fresh. An then the brood will develop, but quite often the brood may develop during that next season, and reach a point where it's very susceptible to temperatures the next winter.

JOHN BORDEN: I've seen the same thing happen here at Chapman Lake and Fulton Lake areas. The beetles probably overwintered in the trees as adults and next spring they started laying their eggs. That summer, Ips attacked the trees as well, then during the overwintering period, the woodpeckers really hammered the brood during the second winter. In the trees the woodpeckers didn't get, the Ips larvae apparently out-competed the mountain pine beetle larvae. And so by the time I looked at them in June, they either had no bark, very few mountain pine beetles, or flourishing Ips brood that out-numbered and out-competed mountain pine beetles.

QUESTION: What kills the tree, the beetle or the Ceratocystis?

GENE AMMAN: We consider it a combination of the two. The fungus plays some role in aiding the beetle in killing the tree, but I think that it's important in regulating the moisture in the tree for the beetle once the tree is killed. Some observations suggested that those trees that have well developed blue stain, tend to remain moister through the entire beetle developmental period than those where the blue stain doesn't seem to be doing quite as well. It may play a role there in moisture regulation that's beneficial to beetle survival.

LES SAFRANYIK: There's a lot of circumstantial evidence as to what's happening there. For instance, a lot of work has been done with conduction of water following infestation in these trees. Most successfully attacked trees stop conducting moisture after about three or four weeks. At that time, all you have are incomplete egg galleries and hardly any larvae hatching. That amount of physical damage would never kill any tree.

In many cases when trees that had only parent galleries and maybe some eggs laid, winter kills all the eggs and no broods develop. The blue stain will, and next year on schedule, these trees still die. So we have this kind of circumstantial evidence that the blue stain definitely had a major role in killing the tree. However, it has many other functions which we don't know yet. For instance, it has a nutritional role. If you don't feed yeast - blue strain fungi - to developing mature beetles, they will never colour up - they'll remain this pale coloured soft insect. But if you feed them this stuff for a few days, they're their normal hardened up selves.

JOHN BORDEN: With mountain pine beetle, the larval galleries are very short, and so while the larvae are deriving some nutrition from the phloem tissue, they very soon make a pupal chamber and they feed for a long time as callow adults without extending any galleries. They must therefore be feeding on fungi and yeast lining the pupal cell, and rely on it for nutrition.

Before we have another question, I want to pursue this just a little bit further. Is the main effect of the fungus to disrupt the xylem translocation, or is it to inhibit the tree's capability to produce resin to pitch out the attacks?

LES SAFRANYIK: The main role of the fungus is to at least locally kill the live cells in the tree, especially the ray cells which are the primary factories for production of secondary resinosis, which eventually could repel the beetles or coat the eggs and prevent their hatching and/or wall off the area around the gallery and isolate the blue stain fungi as well. Resin is a very poor medium for the growth of this fungus. There is a primary mutually beneficial or symbiotic association between the fungus and the insect. The insect benefits by the fungus killing off or preventing resinosis in the tree, and the fungus benefits by getting transportation from place to place, from tree to tree by the insect. The insect has a special structure inside one of its mouthparts for the transportation of the spores of this fungus.

QUESTION: What is known about the biology of some of the parasites and predators, and how likely is it that we'll be able to breed them in the laboratories?

DICK SCHMITZ: There's a good deal more behavioural information that we need to know about most of them in terms of manipulating them. I spoke this morning of the impact of clerids on the mountain pine beetle, and we talked pretty much about what's going on. The clerid larvae feed on the larvae of the beetle beneath the bark, but the adult is also a predator on the adult bark beetle, and, of course, for every adult you keep from getting under the bark, you're getting a good deal more than what the larva is doing on a one-to-one basis with mountain pine beetle larvae. I think the thing that is important to keep in mind is that we don't consider working on these things in an epidemic. That's perhaps the wrong end of the scale to be working on. We ought to be looking at low level or endemic populations and see how we can augment or conserve parasites and predators where they'll have a greater impact.

QUESTION: Is there any difference between the populations of mountain pine beetle which occur on white pine as opposed to those that occur on lodgepole pine?

GENE AMMAN: I suspect that there isn't a great deal of difference. I did a study a few years back and reared the beetles in western white bark, ponderosa, and lodgepole. The source of the beetle was from lodgepole and there was no problem in getting them to go through in those different hosts. But, ideally it would have been nice to have had beetles from each one of those hosts and try them in all the rest of them, and perhaps do some interbreeding.

It seems that at very low population levels, the beetles tend to emerge and attack the same host species from which they came out. I've seen this in white bark pine and lodgepole; but, once an aggregation centre is set up and there is quite a large or moderate population other tree species included in that centre of aggregation will be infested.

PANEL II - DETECTION

AERIAL SURVEYS FOR PEST DAMAGE ASSESSMENT

G. A. Van Sickle[1]

Introduction

To complete annually, regional and national overviews of forest pest conditions and their implications, the Canadian Forestry Service's Forest Insect and Disease Survey (FIDS) has for many years monitored the incidence and damage of insects and diseases in the nation's forests. Aerial reconnaissance and sketch mapping have been a major component of these surveys, especially for mapping of some types of defoliation and tree mortality. Last year more than 225 hours of flying time, much of it in co-operation with the B. C. Ministry of Forests and forest industry, were completed for detection and first-stage mapping of pest-caused damage. Generally, recent bark beetle-killed trees and major defoliator infestations are the specific reasons for the flights but climatic injury, animal damage, some foliar diseases, or unusually heavy cone crops can often be identified.

The purpose of the aerial survey is to complete a regional and nationally uniform estimate of yearly changes in pest types, location, area affected and damage intensity. Also of concern are timelines, continuity during and between outbreaks, and support to research and to subsequent more detailed surveys of areas of specific or operational interest.

Aerial Survey and Mapping Methods

Flying is usually best done in late July or August, by which time field staff have a good knowledge of current conditions and can plan the most efficient coverage of known and historically likely outbreaks. Also, the discolouration or loss of foliage caused by bark beetles or defoliators is usually at its most consistent and visible stage for ease of detection and distinction. With bark beetle-killed pine, the rate of discolouration from green to yellow-red to dull red or grey varies considerably depending on weather conditions after the attack, but by July of the following year experienced observers can usually differentiate between previous year's and older mortality. Correction factors determined during fall cruises can be applied to the estimates if necessary, so that trees retaining red foliage into the second year are not double counted.

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[1] G. A. Van Sickle, Forest Insect and Disese Survey, Canadian Forestry Service, Pacific Forestry Centre.

There are usually two observers, preferably with the senior observer having at least five years experience. With attention to the plane's altimeter, map contours and natural features; the location, relative size, severity and damage and probable cause are delineated on topographical maps. If small, the estimated number of currently damaged trees is recorded, otherwise, severity classes are assigned. In mountainous terrain, contour flying is most efficient with one or more passes through the watershed depending on its size and the light conditions. Observers seated in tandem may be best if several passes are made through a drainage, while one on each side of the aircraft is best if only a single pass is made or if a grid pattern is flown.

High-winged aircraft are selected for safety, ease of forward and lateral visibility (bubble windows greatly improve viewing almost directly below), adequate cruising range and for speed and good performance when mapping is done at elevations of 300 to 500 m above ground level (depending on terrain) and an air speed of 150 to 175 kph. In practice, aircraft such as the Beaver or Cessna 185's or 206's have been most satisfactory. For best concentration and comfort, individual flights should not greatly exceed 3 hours duration. The time of day affects lighting and ease of damage detection, especially on north slopes, so mid-morning flights are usually best. Some observers find that amber IR/UV-filtered sunglasses provide better contrast of colour changes.

For provincial and national overviews, our preferred map scale is the provincial 1:100,000 topographical series which is currently available for about 40% of the province. Alternatives are 1:125,000 or 1:250,000 scale maps. About 100 maps are usually required to cover the infestations throughout British Columbia and Yukon. Pre-flight preparations such as lightly marking the previous year's infestation allow staff to check for errors, increases consistency from year to year and enables the expansions and changes over time to be checked and better identified.

Trials using aerial photos or cover type maps have not been successful for several reasons, including: lack of contrast; difficulty in maintaining location identity at speeds travelled; vast number and organization of base material in confined space of aircraft; older, outdated base material can be confusing; greatly increased flying time or desirability of helicopters; and, higher costs of obtaining, using, storing and reproducing records.

Some oblique, hand-held photogrpahy is usually obtained for a visual record, a training guide, and sometimes to refine the sketch maps and the assessment of damage. Other photographic and remote sensing techniques have been evaluated, but it was felt they could not provide as timely, cost effective and complete an overview as the basic sketch mapping procedure. Last year the operating costs for the aerial survey (excluding staff salaries) was about 10 cents per km^2 (1/10 of a cent per hectare).

In an effort to hasten and improve the reproduction and analysis of aerial survey results, both annually and historically, we have undertaken a development agreement with Northwest Digital Research. A computer assisted mapping system has been installed at Pacific Forestry Centre for trial and development. Data should be more accurately and quickly presented, with facilities to report and analyze by ownership status, or biogeoclimatic units, and utilizing aggregated forest inventory information and FIDS historical records.

Accuracy of Aerial Sketch Mapping

Aerial sketch mapping is widely used and accepted as an initial survey technique for budworms and bark beetles throughout Canada and the USA. The accuracy of the results is often difficult or costly to assess. Also, the general purpose of the different surveys should not be forgotten. Too often, in the absence of more detailed information, sketch map results are extrapolated beyond reasonable limits and expectations. Conversely, time and effort is often spent on detailed surveys when a simple sketch map would have been just as useful.

With experienced mappers, the detection and location of infestations is generally accurate to the scale of map used. For individual trees or small groups, direct observation can even provide better detection than most overview photography. Our own periodic reviews, as well as Aldrich *et al*. (1958) with southern pine beetle, have found aerial sketch map detection and location results to compare very favourably with more careful spot checks or complete surveys.

In sketch mapping, the size of infestation is frequently exaggerated, especially when many small pockets are mapped, but the counts of dead trees are usually low. In comparison to aerial photographs obtained for portions of selected outbreaks, Harris and Dawson (1979) found the total area sketch mapped was 34% larger than measured on photographs.

Conversely, for 26 locations tested, the estimated number of dead trees averaged 35% less than air photo tallies. The variation among locations was high.

Clearly, all aerial observers should be, and usually are, involved in ground surveys to "ground truth" identifications and stand conditions. Of course, with bark beetles, stand cruises are essential to determine the percentage of trees currently attacked and the same cruises should serve as checks on previously killed trees, trees retaining red foliage beyond the first yer of attack, size of trees attacked, brood condition and additional or expected pest problems such as dwarf mistletoe or root rots.

While we continue to seek improved and efficient techniques for timely, annual surveys, we expect that aerial sketch mapping will remain a basic overview method and we will continue to work on improving its consistency and accuracy.

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INFRARED STUDY FOR DETECTION OF MOUNTAIN PINE BEETLE INFESTATION

D. JAMIESON, R.P.F.[1]

Recent research at the University of British Columbia in previsual aerial detection of trees stressed from bark beetle attack has had encouraging results. Hobbs and Murtha (1983) determined that incipient mortality can be detected from green foliaged trees following attack by mountain pine beetle, *Dendroctonus ponderosae* Hopk., (MPB). Levels of accuracy ranging to 90% were achieved using visual interpretation of colour infrared (CIR) 70 mm aerial photographs.

These favourable results encouraged the Ministry of Forests in Smithers, B. C. to implement a pilot study to examine the operational utility of the remote sensing techniques. The study was a joint project sponsored by the B. C. Ministry of Forests, Houston Forest Products Co., and Timberline, with assistance from Dr. P. A. Murtha of the University of B. C.

Study Area

The study area of about 1200 hectares borders the northwest side of Morrison Lake, approximately 70 kilometers northeast of Smithers, B. C. The forest cover consists of mature and overmature stands of lodgepole pine, *Pinus contorta*, Engleman spruce, *Picea engelmanni*, and subalpine fir, *Abies lasiocarpa*, of pure and mixed configuration. The lodgepole pine displayed various stages and intensities of attack throughout the study area.

Field Methodology

The collection of field data and aerial photography was initiated following peak MPB activity, commencing on September 17, 1984 and finishing on September 19, 1984.

Fifty double samples consisting of fixed radius plots were established in stands with green attack lodgepole pine. The plots were marked with 30 cm wide white plastic flagging to assist in location of plots from the air. All trees on plots were stem-mapped and lodgepole pine was quantified as to MPB infestation status.

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[1] D. Jamieson, Timberline, Vancouver, B. C.

Aerial photos were obtained using the fixed base camera and boom system developed by the B. C. Ministry of Forests. The system consists of two metric Hasselblad MK 70 cameras, fitted with 100 mm, f3.5 Zeiss MK Planar lenses, mounted 6.1 m apart on a 7.2 m long boom. The boom is Ministry of Transport approved for longitudinal installation under a Bell 206B helicopter. The equipment was supplied by Timberline. Kodak Aerochrome Infrared Type 2443 film, a false colour, infrared sensitive reversal film designed for aerial photography was used in the study.

The fifty double samples were located from the air and photographed at scales of 1:1,000 and 1:2,000. Six hundred overview stereo pairs at a scale of 1:2,000 were obtained at 100 m intervals along a series of 16 parallel flight times spaced 200 meters apart. Navigation was assisted with the use of 1:20,000 black and white aerial photos and an onboard Loran C navigation system.

The position of all trees on each of the 50 double samples was computer plotted to produce stem maps to assist in the interpretation of the photo plots. The statistics relative to the beetle infestation for the double samples were compiled. Except for the ground information from the training set of four double samples, the results of the ground work were not made available to the interpreters.

Four sets of the double sample photos were classified as 'training photos' on which all MPB attacked trees were identified. These photos served as a benchmark for the interpretation of the remaining photo plots by providing examples of trees displaying crown symptoms of the various damage types as they relate to different attack classes.

The double samples were interpreted and analyzed to generate errors of omission and commission which could be extrapolated and used for error determination over the operational area.

The 1:2,000 overview photo plots were interpreted for MPB attack status and areas of similar attack status delineated and quantified.

Results

The crown symptoms displayed by MPB attacked lodgepole pine were quantified into damage types from the information assessed on the training photos.

The exact double samples were examined to test the interpretation accuracy of the various observers. Dr. Murtha achieved a mean correct percent interpretation of 67% with omission and commission errors of 13% and 19% respectfully. The commission errors were more significant and due to the presence of stress caused by *Ips* ssp. and stem rust, *Cronartium* spp.

For the 33 test plots, there were 376/403 (93.3%) field classified healthy or green attack trees. Both analysis of variance and t-tests indicated that for the population as a whole, and counts of trees by plot on the ground and on the photos, there were no significant differences (p=.01) between field counts and photo counts of healthy and green attack trees. These results suggest that a photo survey would produce similar results to a ground survey in terms of numbers of attacked trees. However, it must be remembered that we are dealing with total populations and tree stands, and not individual trees. On an individual tree basis there are omission and commission error possibilities which must be verified by ground checking. On a stand basis results would be similar but they would not apply to individual trees.

A workshop, conducted by Dr. Murtha, trained three individuals in MPB damage type identification. Two individuals completed the interpretation of the double samples with results similar to Dr. Murtha's, as shown in Table 1.

The overview photo plots on 16 flight lines were interpreted in stands where lodgepole pine was a major species (>20%). A total of 5,800 lodgepole pine trees were evaluated for MPB attack status. Stands displaying similar beetle infestation were outlined as contiguous units and the degree of infestation quantified.

Table 1. Interpretation results of double samples - ground vs photo - different interpreters.[1]

Interpreter	Green Attack % Ground	Green Attack % Photo	No. of Double Samples Examined	% Correct on a Plot Basis
Dr. Murtha	51.5	57.4	33	67
Timberline Trainee	45.3	49.7	28	69

[1] A workshop was conducted by Dr. Murtha on January 21, 1985 to train other personnel in identifying MPB damage types.

Conclusions and Recommendations

The training photos and the analysis of the double sample photos and overview photos provided a great deal of insight into the photo interpretation of MPB attack on lodgepole pine. The conclusions are as follows and relate to scale, film exposure and tree health:

1. Large scale (1:1,000) photos are required to see the 'critical' details of damage symptoms. This conclusion confirms previous findings by Murtha (1983), that foliar details of damage are lost on scales smaller than 1:1,000.

2. Smaller scale (1:2,000) photos provide overviews which are beneficial for stand analysis and show coalesced crown images with the III0b (brighter magenta or halo effect) damage symptom. These symptoms show on a successfully attacked tree when the foliage dies and starts to dry out. Although the foliage is green, the dryness produces a recognizable 'brighter' image.

3. Foliage details are evident at large scales (1:1,000) and spectral differences between foliage age classes can be seen. These differences lead to a variegated magenta pattern and are indicative of healthy or unattacked trees.

4. Successfuly attacked trees show a 'mono-magenta' pattern along all branches. The crown foliage does not show the variegated magenta pattern. If sufficient time has elapsed between successful attack and aerial photography, the dry dead foliage will appear bright (damage type III0b). If the foliage has died and not dried out, the image will be a darker magenta (damage type III0a).

5. Film exposure is critical. Photographs with dye layer densities on the shoulder or toe of the exposure curve are unsuitable for critical photo interpretation. Because of inconsistent weather conditions during this study, about 35% of the photo samples could not be used. As well, the highest levels of omission and commission occurred when under or overexposed photos were used. Prior to photo missions, the IR balance of the film should be tested by requesting a photographic step wedge on an unexposed portion of each film roll. The National Air Photo Library will provide this service and plot a D Log E curve to determine the exactness of the exposures relative to the subjects.

6. The damage to lodgepole pine in the study area cannot be attributed solely to MPB. Overmature and mature trees are particularly susceptible to Ips and rust infestions. The only way to confirm or deny the presence of MPB or other insects or disease is by destructive sampling of the tree. Discussions between Dr. P. Murtha and Mr. W. M. Ciesla (leader, Methods Application Group, USDA, F.S., Ft. Collins, Colo.), an expert in photo interpretation of MPB damage, concerning the magnitude of the commission errors suggests the following:

   (a) The impacts on lodgepole pine are not only caused by MPB. Damage types displayed on CIR photos or lodgepole pine can also be caused by an Ips spp. and stem rust (Cronartium spp.) complex, complicated by overmaturity of the stand. On the same tree, the MPB can attack the lower bole while the Ips damages the upper crown.

   (b) The Ips can kill the tree top (dmage type IIAx or IIA) or the entire crown and cause symptoms similar to MPB.

   (c) The stem rust can kill scattered branches producing clumps of dead foliage (damage type IIIx) and cause symptoms similar to MPB green attack.

   (d) Overmature trees are usually slower growing and can be seen as lighter (IIIOb) or darker (IIIOa) magenta crown foliage images. These effects can be confused with MPB attack.

   (e) Old growth, slow growing trees show thin crowns (damage type IIE). Such thin crowned trees are unlikely to be damaged by MPB unless insect populations are extremely high and all trees regardless of health are being attacked.

7. Experienced photo interpreters using the same training photo set and damage code guidelines produce similar damage assessment results. In this case, three interpreters estimated 67-69% of the lodgepole pine trees correctly as to infestation status.

It is apparent that MPB attacked trees can be previsually identified with low level CIR photography to a level of accuracy that is operationally useful. The interpretive capability can be transferred to experienced operators when on-site training photos are available.

Further assessment based on ground visitation could then be concentrated in the predetermined infested strata. Considering the results of the study, the following recommendations should be considered.

1. Initiate more MPB assessment using CIR in a range of older immature and younger mature stands (ages 80-140) where errors of commisison due to *Ips*, overmaturity, and rust would likely be lower.

2. An operational MPB probe methodology should be developed to incorporate:

   - overview colour mid-level photography (scales 1:10,000-1:15,000),

   - 70 mm CIR photo sampling (scale of 1:1,000); and

   - identification of stressed, green attacked MPB infested trees using the CIR photography.

   Specifically, the overview colour photography would be used to prelocate red attack infestation centres. These infestation areas would then be sampled systematically using large scale, CIR, 70 mm photogpahy. Sampling frequencies ranging from 1 sample per ha to 1 sample per 2 ha are recommended. Finally, the CIR photography would be interpreted for green attack infestations which would form the basis for priorizing and directing ground assessment.

3. When possible, the weather conditions for all CIR work should be consistently the same, preferably high overcast or clear. In the case of rapidly changing light conditions due to scattered cloud, exposures whould be gauged to enhance the interpretation of the crown detail. Furthermore, for interpretation, a slight underexposure of the crown is preferred to overexposure.

4. The IR balance of all film used for CIR work should be quantified by the National Air Photo Library in Ottawa prior to photo missions.

5. Training of industry and MOF staff in CIR methodology and interpretation should be initiated.

INTEGRATION OF PEST DAMAGE DATA INTO THE BRITISH COLUMBIA FOREST SERVICE INVENTORY DATA BASE

R. V. QUENET[1]

Introduction

The forest inventory data base of the British Columbia Forest Service has been designed to provide managers, at both the operational and planning level, with the capability to interrogate, summarize and report on the state and condition of Crown managed lands. The capability to undertake these tasks is well developed and requires only the inclusion of the necessary information to be applicable to pest related problems.

The forest area data base has been designed to include history information and is capable of storing information on insect and disease damage including such parameters as causative agent, degree of disturbance, time of disturbance, duration of disturbance and other parameters. The processing systems that produce area volume statistics are capable of expressing losses in various forms such as volume, growth increment losses and changes in species composition and, through the Computer Assisted Mapping (CAM) system, are capable of inputting and depicting the extent and severity of the outbreak, hazard ratings and other information of interest.

The critical factor in being able to use these systems is the inclusion of pest related information into the existing or modified data structures and to ensure that they are tailored to address the specific needs of resource managers.

Data Definitions

In reviewing the problems associated with the inclusion of pest related information into a data system, it is necessary to briefly categorize the nature of the impact and the procedures used in detection, qualification and mapping pest outbreaks.

The impact of pests generally fall into two categories, namely, mortality losses and growth increment reductions. This distinction is of particular importance as the treatment of the basic inventory data differs significantly.

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[1] R. V. Quenet, Planning and Inventory Branch, B. C. Ministry of Forests.

Mortality losses cause stand changes including such factors as species composition, density, stand structure, diameter distributions and productivity. Impact estimation is therefore dependent on being able to quantify the changed stand characteristics through forest classification and on developing modified yield estimates through sampling of affected stands.

Growth increment reductions directly affect productivity but generally do not cause stand characteristic changes. Volume loss estimation is dependent on the development of yield estimates for affected stands and comparing these estimates with those obtained from unaffected stands.

Pest detection techniques vary widely depending on the purpose of the survey and the procedures used. They range from recording the incidence of the pest to damage mapping, both of which may be carried out at levels ranging from intensive, site specific investigations to broad reconnaissance surveys. The type of survey affects the precision and accuracy of the information gathered, the ability to relate the information to existing inventories of the forest resource, the ability to determine the effect on current and future yield estimate and economic values, the selection of prevention and control procedures, and the determination of areas at risk.

Integration of Pest Information with Forest Inventories

Boundary Delineation

The ability to delineate the boundary and area of damage is an essential first step in determining the extent of potential volume and economic losses. This requires a geo-coded mapping system linked to both forest stand attributes and pest information attributes. The current forest inventory data base with its associated computer assisted mapping system provides such a vehicle and can be used immediately and, as the requirements expand, specifically designed applications can be developed to meet user needs. However, it is critical that the procedures employed to delineate areas of attack provide data in a form that can be incorporated into the mapping system and that the data meet acceptable standards of reliability and accuracy.

Damage Assessment

Following the definition of the boundary of attack, it is necessary to quantify the severity of impact. The information requirement here depends on the type of impact, mortality or increment loss.

In the case of mortality losses it is necessary to restratify and reclassify the affected stands. Information requirements include species composition, age, height, density or crown closure, stocking and other related parameters.

For stands suffering from increment losses some direct population information would be required. If pest population statistics are used, a mechanism for converting these figures to increment losses would need to be developed.

Yield Losses

The estimation of yield losses, both immediate and long term, requires the development of modified yield tables which can express yield losses at various levels of impact. Again, the procedures for the derivation of this data is a function of the type of loss, mortality or increment.

A number of approaches can be taken in the derivation of yield losses associated with mortality. These range from the establishment of samples representing various levels of mortality to using the currently existing sample data base but allowing the selective definition of individual trees, depending on the intensity of attack, which would be counted as dead. This procedure can be applied at the stand table level or to individual samples. The latter method, while relatively crude, would provide immediate data which could be verified and subjected to statistical and sensitivity analyses and would be available at the least cost.

The determination of the impact from damage that results in increment losses is somewhat more difficult to quantify as it normally requires the determination of historic attacks as well as current attacks through destructive sampling. However, a factored approach could be applied in the short term to allocate losses on a stand basis.

Linkages

The structural linkages between stratification, classification, stand attribute descriptors, computer assisted mapping, statistics generation and reporting capabilities are well developed and can be applied to pest related information provided that it is available.

The availability of the above capabilities would provide a short-term capability to express losses on a quantative basis and form the foundation for the assessment and development of more detailed and sensitive procedures for the mid- and long-term assessment of pest losses.

Conclusions

The existing forest inventory structures and facilities will allow the integration of pest damage information and provide the capability to process this information as an integral part of the inventory. This capability will assist in the development of T.S.A. Plans, yield calculation, A.A.C. determination as well as operations.

The inclusion of pest information will significantly improve the capability to manage the forests of the province.

INTERPRETATION OF
LARGE-SCALE COLOUR-IR PHOTOGRAPHS FOR
BARK BEETLE INCIPIENT ATTACK DETECTION

Peter A. Murtha[1]

Introduction

The remote detection of green-foliaged, bark beetle successfully-attacked (killed) conifers has eluded foresters, entomologists, and remote sensors for decades (Gimbarzeusky, 1984; Henninger and Hildebrandt, 1980). Remote detection methods have primarily used aerial sketch-mapping, and have concentrated on locating trees with faded foliage, red crowns or defoliated trees (Harris *et al*., 1983). Outbreaks have been considered difficult to detect *since the* foliage does not fade or turn colour until a year after attack (Furniss and Carolin, 1977). Aerial sketch mapping cannot be used to diagnose new attacks. Ground probes are used to locate and identify new attack when trees still maintain a full complement of green foliage through detection of brown boring dust around the base of the tree for spruce bettle, *Dendroctonus rufipennis* Kby., or pitch tubes for mountain pine beetle, *Dendroctonus ponderosae* Hopk., or by removing bark to search for feeding galleries for both. Early detection of beetle attack would make forest management and beetle control more efficient. Early detection means finding green or current attack (successfully attacked and killed trees) as soon as possible after attack and before the foliage fades, turns red brown or drops off. The purpose of this paper is to describe a photo interpretation technique that can be used to identify green attack. Two case studies are used to support the interpretations through indepenently collected ground reference data.

Background

Bark Beetles : The Entomological View

The life cycles of both the spruce beetle and mountain pine beetle have been well documented (Furniss and Carolin, 1977; Johnson and Lyon, 1976), and the entomological viewpoint of the impacts on conifers have been well described (Davidson and Prentice, 1967). Survey techniques have been developed based on these impact impressions. Safranyik *et al*. (1982) described the mountain pine beetle (MPB) impact as *follows*:

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[1] P. A. Murtha, Faculty of Forestry, University of British Columbia, Vancouver, B. C.

> "Green trees are attacked by the mountain pine beetle in mid-summer. The first noticeable foliage colour change usually occurs in spring of the following year. Occassionally, following an early attack and a hot, dry summer, crowns will begin to fade in the fall. The foliage changes from green to yellow, to yellow-brown, to red-brown, and then drops off the tree. In June and July of the year after attack, trees are usually yellow-green or yellow-brown."

They follow this description of foliage colour changes with the statement that:

> "This change in foliage permits detection from the air, lookout towers or other vantage points. However, trees killed by an agent, including beetles, usually show the same sequence of colour changes and, therefore, a ground survey must be done."

According to Furniss and Carolin (1977), after a spruce has been attacked by the spruce beetle (SB) and dies, the foliage fades during the summer, and/or through the following winter. (It does not turn red-brown as do lodgepole pine, *Pinus contorta* Doug., attacked by mountain pine beetle.) The foliage first falls from the branch ends and the outer portions of the crown since it is exposed to the elements and is more readily knocked off. Defoliated trees have been called "grey" attack.

Wood and Van Sickle (1983), and Wood *et al*. (1985) categorized both MPB and SB attack into the following five categories for insect survey and report summary purposes:

1. Healthy - no beetle attack;
2. Current - attack presumed successful in the year of the survey, the tree foliage is still green. This stage is sometimes called green attack; determined on the ground;
3. Red - for MPB - - successful attack occurred in the year prior to the survey, and
    - for SB - - the atack occurred two years prior to survey
    - for both insects, the folige has turned red-brown, but this situation is rare for SB attacked spruce;

4. Grey - the trees are defoliated and were successfully attacked at least two years prior to the survey;
5. Partial or Strip Attack - attack is not considered successful, the trees display visually green foliage, and are frequently re-attacked the following year. Strip attack is determined on the ground by removing some of the bark from the tree trunk.

A final category is also used by the ground survey crew to describe a tree which successfully overcomes the attack by the beetles by overwhelming it with excessive production of resins and pitch. When this happens, the beetle is described as "pitched out" and the attack is thought to be unsuccessful. The red and grey categories have been mapped by aerial sketch-mapping (Harris _et al_., 1983) or by photo interpretation (Klein, 1982), but the other categories (healthy, current or green, partial or strip, and pitch-out) have required data from ground surveys (Safranyik _et al_., 1982; Wood and Van Sickle, 1983).

Bark Beetles : The Air Photo View and Healthy Trees

It is clearly evident from insect survey reports and research papers on photo interpretation of bark beetle attacks that the early stages of attack (which includes current, green, strip attack and pitch out) produce no obvious visual symptoms of attack, otherwise they would have most certainly been reported in the literature (Gimbarzevsky, 1984). Puritch (1981) after an analysis of the pertinent literature reported that there were many unsuccessful attempts in the 1960's and 1970's to detect the early stages or bark beetle attack, and concluded, " . . . bark beetles . . . do not cause immediate changes to the appearance of the tree and consequently remain undetected through early infestation stages." The time period for the early infestation stages applies to that time period between the initial successful beetle attack and visual appearance of obviously faded foliage, which generally occurs almost a year later in the spring following the mid-summer attack. These faded crowns have been nick-named "faders" and generally preceed the red-brown foliage phase of MPB attack or loss of foliage after SB attack.

However, it is perceived by this author that one of the major problems in the application of aerial photographic and interpretation techniques to the evalution of bark beetle impacts is that the small photographic scales (1: 6,000 and smaller) have permitted interpretation of only the more obvious faded, red, and grey attack categories. Spencer (1984) reported that larger scales (between 1:4,000 and 1:2,00) were required to interpret dieback in Australian eucalypt forests, that scales between 1:3,00 and 1:2,500 were required to make interpretations on medium-sized branches, and that a scale of 1:500 was required to assess leaf and twig patterns. Murtha (1983) noted that a 1:4,000 photo-scale sufficed for counts of dead trees, but 1:1,000 photos were required for the photo interpretation of subtle strain symptoms which included thin crowns (premature loss of older foliage), scattered clumps of yellowed or red-brown foliage, and darker or lighter magenta hue variations of foliage in a crown on colour infrared (CIR) photos. Because of these perceptions it was decided to formulate a scenario which would describe the crown condition, and sequence of symptoms possible for a tree successfully attacked (killed) by bark beetles.

The first part needed the description of a healthy conifer. On colour infra-red (CIR) photos, the average magenta-hued trees were considered to be normal. Darker (IIIOa) and lighter (IIIOb) magenta-hued variations (Murtha and McLean, 1981) were shown to be vigour variations of the normal tree. (The coding for the darker and lighter variations is after a key to forest "damage types" presented by Murtha [1981, 1978]). These darker and lighter variations are noted best at large scales (1:1,000) and even at 1:4,000, misinterpretations can be expected (Murtha 1983).

After the examination of 624 ground-checked spruce (Murtha 1985) and over 200 ground-checked pine (Hobbs and Murtha 1984) followed on multi-temporal CIR photographs from 1981 to 1984, a second obvious pattern for a healthy tree has emerged. On both normal (healthy) non-beetle-attacked spruce and pine, there are hue variations along the branch. I have called this pattern a variegated magenta (VM) pattern for CIR photos and variegated green (VG) for normal colour (NC) photos.

Sometimes the variegated patterns are seen associated with generally darker (IIIOa) or lighter (IIIOb) magenta-hued crowns. Hence for healthy or unsuccessfully attacked trees there are three "damage types" designations, VM, VM/IIIOa, and VM/IIIb (Table 1). For the CIR large-scale aerial photographs the unattacked trees displayed a range of tones within the magenta hue along each branch. Careful observation is needed to preclude possible confusion with contained shadows in the tree crown. The folige on the branch tips is a light magenta while the inner foliage is a darker magenta. On some trees, as many as 3 steps of magenta tones can be seen. Some conifers maintain several years worth of foliage, and each year as the foliage grows older, it becomes darker, or less reflective at all wavelengths. Steiner and Gutermann (1966) documented this fact for pine and spruce. The different age classes of foliage produce the variegations along each of the branches. The visual impact is a salt and pepper appearance to the foliage of the tree crown.

TABLE 1 - Description of "damage types" for the photo interprettion of large-scale (1:2,000) colour-infrared aerial photographs of unattacked spruce or pine.

Photo Interpretation Category (Damage Type)	Description
VM	"Variegated magenta"; these are unattacked trees. The crown and branches have a mottled variegated appearance, usually with light-pink magenta branch ends and darker magenta toward the tree trunk. Some very light straw hues may be present on the inner part of the crown. The overall crown hue may be lighter or darker than other trees, but note the tonal variation. Do not confuse contained crown shadows as part of the tonal variation which occurs along the illuminated branch and is caused by spectral reflectance differences from foliage in different age classes.
VM/IIIOa	These are "VM" trees as described above, however, the overall crown magenta hue is somewhat darker than normal. [This is a similar pattern as that described by Murtha and mcLean (1981) for Douglas-fir.]
VM/IIIOb	These are "VM" trees as described above, however, the overall crown magenta hue is light magenta to somewht pink. [This too is a similar pattern as that described by Murtha and McLean (1981) for Douglas-fir.]

Because of the natural stress of poor site, some trees suffer premature loss of older foliage, - - that is, they may only maintain two live foliage age classes. The oldest age class dies in the third year, turns red brown and eventually drops off. The fact causes another pattern:

Foliage Age Class	Tone and Hue
current	- light magenta
2nd year foliage	- medium dark magenta
3rd year foliage (dead and red-brown)	- straw yellow

Recognition of the above patterns provides another clue to a normal, unattacked, or unsuccessfully attacked tree, which is under the influence of site stress (Table 1).

Beetle Attacked Trees

For successfully-attacked trees, two patterns have been observed. The first pattern occurs within a couple of weeks after attack. When a tree has been killed by the beetle and its associated Ceratocystis spp. fungus, the foliage dies, dries, chlorophyll breaks down and the foliage eventually losses its greenness. Similar to a cut Christmas tree in a house, the foliage along each branch becomes the same green tone since spectal reflectance differences among the different foliage age-classes are lost. The variegated tonal pattern is lost, and the absence of this pattern can be interpreted on large scale CIR photographs. The non-variegated pattern is most evident in the upper tree crown and is virtually imposible to see from the ground. When compared to unattacked trees the foliage usually appears darker, and somewhat tannish. These attacked trees have been designated as III0a-T (darker magenta-tannish) (Table 2). The tan hue is not present in all cases, but the lack of the variegated pattern is essential to observe.

TABLE 2. Description of damage types for the photo interpretation of large-scale (1:2,000) colour-infrared aerial photographs of bark beetle attacked pine or spruce.

Photo Interpretation Category (Damage Types) [with beetle attack status]	Description
IIIOa-T [Current, green or Strip Attack]	The foliage is decidedly darker than normal magenta to tan-magenta. Tonal mottling is not evident. Foliage on each branch has a similar hue and tone. Contained crown shadows will be present. Successful beetle attack occured in current year.
IIIOb-H [Current, green or Strip Attack]	The foliage is decidedly lighter than normal. The foliage may be so light that it appears whitish, or off-white, and the crown and branches appear to have a "halo" appearance. Tonal mottling is not evident. [To the ground observer these trees still display visually green foliage, but it appears totally different on air photos.] Successful beetle attack occurred in current or previous year.
IID [Grey attack] Spruce bettle	The crown has lost dead foliage from branch tips, and some usually light toned foliage remains. Various degrees of defoliation may be evident but the inner branches will be obscured because of residual foliage. This is the early part of the grey-phase classification of beetle attacked trees. Beetle attack is most likely two years old.
IIIG [Red attack] Pine	The foliage has turned red-brown and is seen as yellow or straw yellow on CIR photographs. MPB attack occurred in the previous year.
IB [Grey (dead)]	The crown is defoliated, the twigs and branches are grey. The tree has been dead for more than 2 years.

For the unattacked trees, 72/95 (75.8%) displayed a variegated magenta pattern in the foliage. For the green attack trees 63/93 (76.3%) fell into the IIIOa-T or IIIOb-H categories. Unattacked trees which fell into either of these categories were commission errors, in that these trees displayed symptoms common to attacked trees, but the ground data said no attack. For the total population commission errors amounted to 12.2% (23/188).

Given sufficient time and dry weather conditions, successfully attacked trees start to glow like a "halo". The loss of greenness, the dryness, and the lack of spectral variation among foliage age-classes produce light-toned, highly reflective, mono-hued tree crowns which are highly reflective. These successfully attacked trees have been designated IIIOb-H (lighter magenta-halo) (Table 2). Even though these trees stand out with marked contrast from other unattacked trees, they can be misjudged on the ground without destructive tree sampling. Murtha (1985) reported that during a study of spruce beetle attack, and using the damage types as described in Tables 1 and 2, photo interpretation had suggested 68 (93.1%) of 73 trees had been successfully attacked and therefore killed. This conclusion was not corroborated by the 1983 field data which indicated that the beetle had been successfully "pitched-out" and the trees would survive. The photo interpretation was confirmed a year later during the following field season when the trees were found dead.

The variegated magenta theory was also applied to the mountain pine beetle attacked stand used in the Hobbs and Murtha (1984) study. On the 1:2,000 CIR photos, 188 pine were re-examined by photo interpretations. The results are presented in Table 3.

Trees which were described as having a variegated magenta pattern, and as being green attack, are misses or omission errors. For the total population omission errors were 15.9% (30/188). [Omission errors can be expected to be high since the time required for crown foliar symptoms to develop after successful attack is generally unknown, and reported to be as long as one year (Safranyik _et_ _al_. 1982)].

TABLE 3. Photo interpretation vs. beetle attack status from ground data of a mountain pine beetle infested pine stand. Aerial photography August 18/81; ground check May 25/82. Numbers in Table are from interpretation of the air photos.

Photo Interpretation Damage Type		Beetle Attack Status				Total Trees
		Unattacked		Green Attack [1]		
		No.	%	No.	%	
Unattacked	VM	53	72/188=38%	25		78
	VM/IIIOa	2	or	2	30/188=15.9%	4
	VM/IIIOb	17	72/95=53.8%	3		20
Attacked	IIIOa-T	9		26		35
			23/188=12.2%		63/188=33.5%	
	IIIOb-H	14		37		51

[1] Green attack was verified on May 25, 1982 through examination for pitch tubes and boring dust. No bark was removed, but by September 1982 the trees had red crowns.

Management Implications

The management implications are obviously open to discussion and debate; but it is suggested here, that with proper application, large-scale photos and photo interpretation can be used to help manage beetle infested stands. Firstly, they can be used as a sampling tool to monitor forest stands. The correct sampling procedure needs to be developed. The large-scale photos should be used in conjunction with smaller scale, overview photos which would clearly show red, grey and old attack. Once suspect areas have been identified, ground probes can be used to collect further beetle population data and large-scale photos can be obtained and used to assess tree condition without destructive sampling. The second and most important implication is that tree condition and hence successful beetle attack may be easier to interpret from the large scale photos than it is (without destructive tree sampling) on the ground (Murtha 1985). As forest management progresses into single-tree "silvicultural" management for beetle infested stands, assessment of condition becomes more critical. With large sums of money being spent to remove single infested trees, it seems that interpretation results of large-scale CIR photo should become part of the management decision.

Conclusion

Recent results from the photo interpretation of large scale (+1:2,000) colour-infrared photos for early stages of bark beetle attack have indicated that:

1. a variegated magenta pattern indicative of tonal variation on the foliage means a normal or unattacked tree;
2. successfully attacked trees have non-variegated monotoned crowns which at first are dark magenta to tannish (IIIOa-T); and,
3. foliage on successfully attacked trees dries out and becomes hightly near-infrared reflectives while it is still visually green. Such tree crowns grow like a halo (IIIOb-H) and stand out in marked contract to unattacked trees.

Acknowledgements

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QUESTIONS

QUESTION: Is the use of 1:10,000 colour photography an effective way to look at setting priorities from an operational point of view?

DAVID JAMIESON: Our recommendation for the use of any infrared detection techniques would be tied to the use of a 1:10,000 overview scale colour photography to stratify any visible areas of infestation sources and then sample around them. This is preferable to blanket sampling of timber types with a potential for infestation without addressing where, in fact, the visible infestation is at this time. The two levels of photography go hand in hand. Stratification either by 1:10,000 colour photography or conventionally done with sketch-mapping on an operational basis, forms the basis for the sampling design for any further detection efforts.

COMMENT: I would like to make one point about the colour photos that bears more on what's happening tomorrow than today. We're going to be able to tell fairly nicely how well our control projects are working, in terms of single tree disposal and logging, if we have several years of photography. Comparisons over time might be very interesting.

QUESTION: Could I just ask about the 67% accuracy mentioned in the papers presented? I'm interested in what you think the value of 67% accuracy is - is that level essential, or would you be happy with lower levels, and what's necessary to make it operational?

DAVID JAMIESON: I'll answer first that one shouldn't confuse the 67% absolute accuracy on a tree-to-tree basis with the results on a stand basis, which showed no significant difference. I'd also answer the question in another way. This study was the first operational study of this size to my knowledge in British Columbia. It was demonstrated that this stand had other problems in it which possibly caused stress which might be misconstrued to be mountain pine beetle attack. It's operational in the sense that in this particular project it worked quite well. Obviously a range of age classes should be tested, particularly in those stands in which other causes of stress aren't evident and, in fact, one might get to the point of achieving the level of accuracy that some of the research work got at UBC.

ROBIN QUENET: I'd like to make a comment on this as well. In looking at the results of this study, I was quite impressed, and there are accuracy figures associated with it. Now my questions would be if one looks at the alternative techniques available, which I presume is ground probing, what is the accuracy that one achieves with that, in terms of errors of omission and commission. I think that some sort of comparison along that line would be quite interesting. I suspect that the two techniques are probably giving very similar results and I suspect that what one would end up having to do would be to look at the comparative costs. I would like to see that done, because I think there is a real possibility with this technique, and I think it holds great promise.

PANEL III - MANAGEMENT OPTIONS AND CHALLENGES

METHODS FOR USE OF SEMIOCHEMICALS AGAINST THE MOUNTAIN PINE BEETLE, DENDROCTONUS PONDEROSAE

John H. Borden[1]

Colonization of Trees by Bark Beetles and Their Insect Associates

Bark beetles are the principal lethal agents of coniferous trees over much of western North America. Basic research over several decades has addressed various components of host selection by these tree-colonizing insects and their associates. Critical to the success of host selection is the role of semiochemicals.[2] These include:

- pheromones, semiochemicals that convey a message between members of the same species;
- allomones, interspecific semiochemicals of adaptive advantage to the emitter; and
- kairomones, interspecific semiochemicals of adaptive advantage to the perceiver.

A model has recently been developed that integrates five semiochemical-mediated components into an overall system, and identifies six points of vulnerability through which the system could practically or potentially be subverted or exploited by mankind (Figure 1) (Borden 1985, and references therein).

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[2] From the Greek word semeon, a mark or a signal, i.e. a message-bearing chemical.

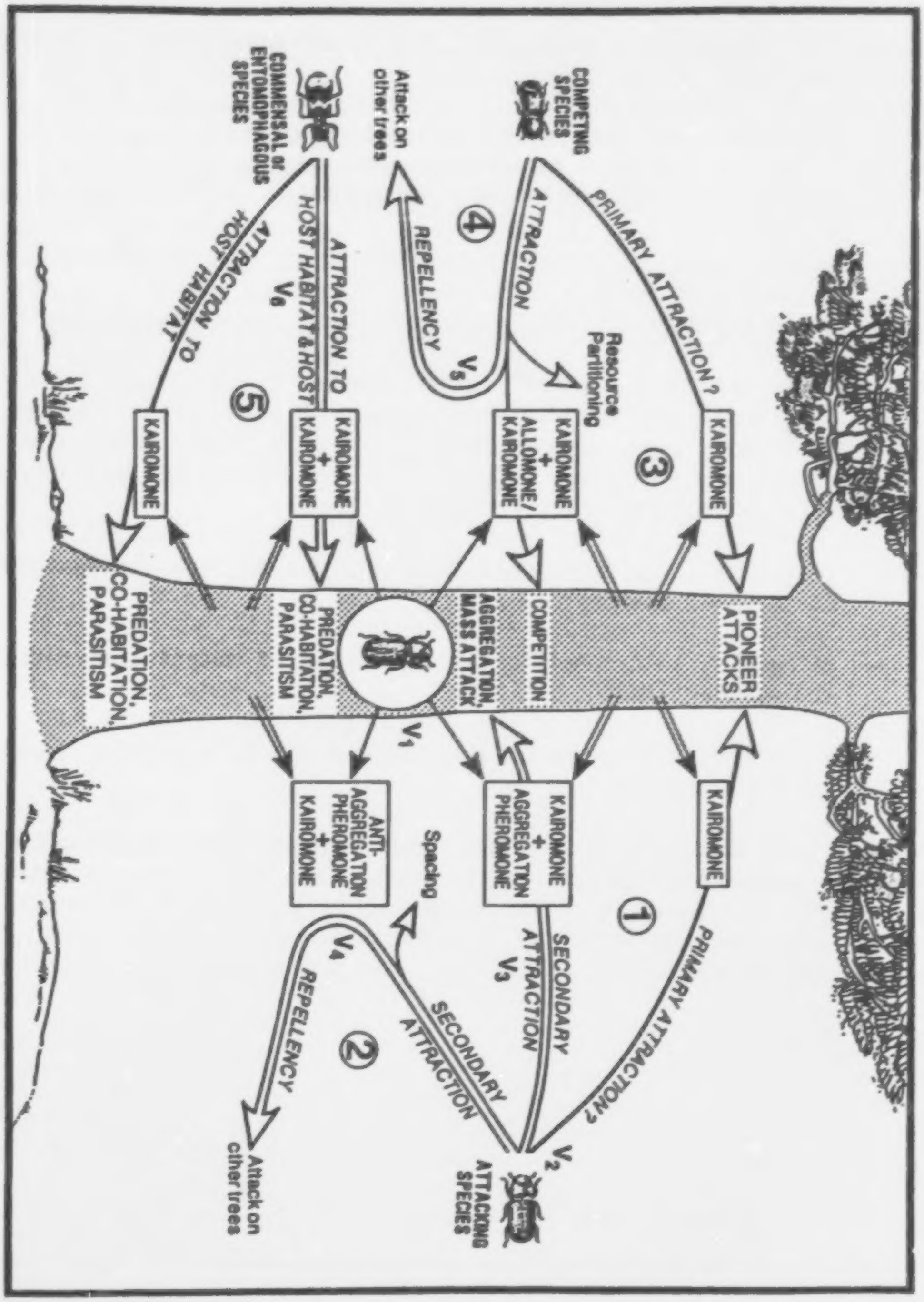
COMPETING SPECIES
Attack on other trees
COMMENSAL or ENTOMOPHAGOUS SPECIES
PRIMARY ATTRACTION?
ATTRACTION
④
REPELLENCY
V_5
Resource Partitioning
③
KAIROMONE
KAIROMONE + ALLOMONE/ KAIROMONE
ATTRACTION TO HOST HABITAT & HOST
V_6
ATTRACTION TO HOST HABITAT
⑤
KAIROMONE + KAIROMONE
KAIROMONE
PIONEER ATTACKS
COMPETITION
AGGREGATON, MASS ATTACK
PREDATION, CO-HABITATION, PARASITISM
PREDATION, CO-HABITATION, PARASITISM
V_1
KAIROMONE
KAIROMONE + AGGREGATON PHEROMONE
ANTI-AGGREGATON PHEROMONE + KAIROMONE
Spacing
①
SECONDARY ATTRACTION
V_3
V_4
②
REPELLENCY
SECONDARY ATTRACTION
PRIMARY ATTRACTION?
V_2
ATTACKING SPECIES
Attack on other trees

Figure 1. - Schematic diagram depicting five ways (circled numbers 1-5) in which semiochemicals can influence bark beetle populations, and identifying six points of vulnerability (V_1-V_6) through which semiochemical communication by bark beetles and their insect associates can be subverted or exploited by mankind.

The five semiochemical-mediated components of the colonization process (Figure 1, Nos. 1-5) are identified in the model as follows:

1. Aggregation and mass attack on new hosts (No. 1)
   The first-arriving (pioneer) beetles may find the host tree through a primary attraction to host kairomones, through visual responses, or both. They then release aggregation pheromones which act in combination with host-produced kairomones, usually monoterpenes or ethanol, to induce secondary attraction and a resultant aggregation by many beetles on a tree.

2. Cessation of aggregation and shifting of attack to unexploited regions of the host or to new hosts (No. 2).
   To avoid over-allocation of the host resource, anti-aggregation pheromones are released by beetles of either or both sexes. These semiochemicals function in part to space attacks evenly over the habitable area of a tree, and when the tree is saturated, to shift attack to a new host.

3. Induction of aggregation by species that compete for the same host resource (No. 3).
   Competing species may orient to the same host tree as the attacking species in response to visual stimuli or kairomones from the host tree, or by utilizing as host-finding kairomones semiochemicals released by beetles of the attacking species. At close range the attractive kairomones may serve as allomones for the attacking species, causing the competitors to move to other areas of the tree, thus partitioning the resource.

4. Inhibition of aggregation and attack by species that compete for the same resource (No. 4).
   The allomonal effect of semiochemicals released by beetles of the attacking species may deter attack by a competing species. Thus a host resource may be exclusively claimed by the first-attacking species.

5. Mediation of host finding by commensal and entomophagous insects (No. 5).
   A tree under attack by bark beetles may be an olfactory beacon for commensal insects that inhabit bark beetle galleries or for entomophagous insects that prey on the bark beetles outside or inside of their galleries.

The six major points of vulnerability (Figure 1 V_1-V_6) in intra- and interspecific communication by bark beetles and their associated insect species can also be identified. In turn, these points of vulnerability lead to six fundamental management strategies:

1. Prevention of production of aggregation pheromones (V_1).
2. Sabotage of olfactory perception (V_2).
3. Exploitation of semiochemical-based secondary attraction (V_3).
4. Exploitation of anti-aggregation pheromones (V_4).
5. Exploitation of repellent allomones (V_5).
6. Exploitation of the kairomonal response by entomophagous insects (V_6).

The availability of synthetic semiochemicals (Borden 1985) has made it possible to develop pest management tactics whereby these strategies can be implemented. The first, third and fourth strategies have been applied successfully through various tactics on several species of bark and ambrosia beetles (Borden 1985). My research has focused primarily on the third strategy. It is my philosophy that the closer nature can be simulated by mankind, the greater chance there is that "natural" controls will be successful. Attracting bark beetles to semiochemical-baited, tree-trunk simulating traps has a good chance of success. There is an even greater probability of success if beetles can be induced to attack semiochemical-baited trees. The main difference from the natural state is that humans selected the trees so that attacks by the beetles are compatible with forest management plans.

Exploration of Semiochemical-Based Secondary Attraction Against the Mountain Pine Beetle

A. Available Material

Three semiochemicals are used by the mountain pine beetle to mediate secondary attraction (Conn et al. 1983; Borden et al. 1983a). These are:

- *trans*-verbenol, a female-produced aggregation pheromone;
- *exo*-brevicomin, a male-produced aggregation pheromone; and
- myrcene, a tree-produced kairomone that synergizes (activates) the attractiveness of the two pheromones.

These semiochemicals can be used to bait multiple-funnel (Lindgren®)

traps or to bait trees so that attack will be induced. Traps, trap baits, and tree baits are available commercially.

B. Population Monitoring

Baited traps can be set up to determine when beetles are flying and to implement no-haul restrictions (Stock 1984). This can be done when there is a danger of new infestations arising from beetle-infested logs in transport or in the mill. When a trap-based monitoring system is set up, it may be calibrated by comparing catches in traps with attacks on semiochemical-baited trees.

C. Containment and Concentration of Infestations

Research has shown that baiting one tree every 50 m on a grid basis within an infestation (4 trees/ha) will restrict emigration of beetles and induce dispersing beetles to enter the baited stand (Borden *et al*. 1983a; D. R. Gray[3], pers. comm.)

The result of this tactic is to cause many attacks on and around the baited trees, intensifying the infestation within the baited area. This containment and concentration technique can be used to treat infested stands that cannot be logged in the current year. It probably can be repeated for a second year. However, it is critical that the infested trees be logged and removed to the mill as soon as possible! The beetles are then killed in the debarker.

D. Pre-Logging Baiting in Lightly-Infested Stands

Lightly-infested stands, or clean but high hazard stands, can also be baited on a grid or perimeter basis, when infestations are scattered throughout an area (Borden *et al*. 1985). Attack may be concentrated and contained within the baited area. Build-up of populations may then be prevented by removing the infested trees to the mill each year. If no attack occurs on or around the majority of baited trees, the manager should have some measure of confidence that the beetle problem is under control.

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E. Post-Logging Mop-Up of Residual Infestations

Both selective and clear cuts to remove beetle-infested trees may fail to remove all of the target trees. Research has shown that residual populations of beetles emerging from these trees can be concentrated on and around semiochemical-baited trees (Borden et al. 1983c). The newly-infested trees can then be removed in a small timber sale or subjected to single tree disposal. More than one year of treatment may be necessary. After a spring, 1982, selection cut of 5,000 infested lodgepole pines in Manning Park, 50 trees were baited the following summer, and 166 trees, including 48 of the baited trees, were attacked and removed. The following year, there were 10 trees baited and 29 attacked and removed. The third year there were 6 trees baited and only 3 trees attacked and removed.

F. Snuff-Out of Spot Infestations

Following a basic research plan over the last two years, a large-scale trial can be repeated for a second year. However, it is critical that the operational trial for 21-30 tree spot infestation is planned in 1985 for two techniques: CUT, SPRAY, BAIT AND TREAT, and BAIT AND TREAT. The CUT, SPRAY, BAIT AND TREAT technique involves the following steps:

- Felling of all trees containing brood beetles in a spot infestation, usually in June or July.
- Treatment to run-off around the bole to the height of attack with Sevin XLR® (carbaryl, 2% a.i. in water) applied from a backpack sprayer.
- Semiochemical baiting at least half as many green trees as felled trees surrounding the spot, taking care to bait the majority of trees in the direction the spot appears to be moving.
- Treatment of all attacked trees with MSMA (monosodium methane arsonate, half or full strength) applied at 1mL/2.5 cm circumference to an axe frill at the base of the tree within four weeks of attack. Expert crews may not need to treat a tree attacked so lightly that the tree will survive.

The BAIT AND TREAT technique eliminates the first two steps. It is easier to do, but more trees are attacked and need to be treated with MSMA.

Any use of these techniques should be considered to be operational trials at present, but forward-looking managers may wish to try them even though the background research is not yet completed.

Conclusion

Semiochemicals are a powerful new tool that can be used effectively against the mountain pine beetle. However, it should be emphasized that there is no substitute for sound forest management that minimizes or eliminates the problem by such practices as hazard rating of stands, harvesting trees when they reach maturity, creating uneven-aged mosaics of timber stands, partial cutting to "beetle proof" susceptible stands, and favouring of non-host species (Safranyik *et al*. 1974, Amman *et al*. 1977). Conventional single tree disposal (cut and burn) may be very effective (Hall 1985), as may a new, debarking tree monkey currently under development (Moulson 1985). Ultimately semiochemicals will be most effective when their use is judiciously integrated with other forest management or pest management procedures.

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STAND HAZARD AND RISK RATING
FOR MOUNTAIN PINE BEETLE SUSCEPTIBILITY AND LOSSES

Mark D. McGregor[1]

Introduction

Because of the recurrent losses caused by the mountain pine beetle (MPB), Dendroctonus ponderosae Hopk., in the western U. S. and Canada, managers have less than a 50 per cent chance of growing lodgepole pine, Pinus contorta var. latifolia Engelm., to 40.6 cm diameter in most lodgepole pine stands and in most cases, less than a 25 per cent chance (Roe and Amman 1970). Consequently, forest managers commonly ask two questions: "Which lodgepole pine stands are most susceptible to the mountain pine beetle?"; and, "How many trees will I lose if and when the stand becomes infested with the beetle?" The first question is addressed in several published management guidelines (Amman and others 1977; Cole and Cahill 1976; McGregor and others 1985; Safranyik and others 1974). The second question depends on the rate and amount of loss during an infestation (Cole and McGregor 1983).

It appears that there are important steps in the development of a forest pest management system: (1) determination of pest impact; (2) identification of when and where damage will occur; (3) are there other resource values pest managers should be concerned about other than bugs and trees; and, (4) determination if cost effective, environmentally and socially acceptable methods of pest population management exist (Hedden 1981; McGregor and others 1985).

Quantification of impact requires a detailed understanding of the existing forest resource management regime. This knowledge is necessary in order to accurately evaluate social, environmental, or economic effects of pest damage. Lack of understanding can lead to either under or over-estimates of damage (Hedden 1981).

Knowing when, where, and how damage will occur is necessary to forecast trends, damage to various resource values, and for development of a reliable pest management system, particularly when the system emphasizes prevention. Predicting where significant damage will occur will also lead to a more efficient system of remedial control (Hedden 1981).

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Identifying where damage will occur is usually considered the realm of hazard rating, and many hazard rating systems are based upon a good understanding of pest population dynamics.

If the pest population threatens valuable stands of timber in high-use recreation areas, elk summer range, or if cutting to reduce potential pest impact threatens soils, water quality, and fisheries in specific management units, other workable management should be integrated with logging to reduce impact on other resource values and minimize losses from the target pest.

Once we identify the hazard of various stands and if damage will be significant, then we can develop a cost effective, environmentally and socially acceptable integrated strategy for management of the beetle. The system can include both remedial and preventive methods. The system developed must be compatible with the prevailing management objectives and will be an integrated component of the management program.

This paper briefly describes the various hazard- and risk-rating systems, implementation of the Amman and others 1977 hazard-rating system, and Cole-McGregor 1983 risk-rating model in Region 1; and briefly describes preliminary results of data collected in 1984 in fulfillment of one Action Item for the Canada-U.S. Mountain Pine Beetle Project.

Hazard- and Risk-Rating Systems

Effective hazard- and risk-rating systems for assessing susceptibility of unmanaged lodgepole pine stands to the MPB are essential in designing and accomplishing sound multiple resource forest management objectives.

Which of the lodgepole pine stands are more susceptible to beetle outbreak and how many trees will be killed depend upon risk (Safranyik 1982). Reliable methods are not available to predict when an outbreak will develop (Shrimpton and Thompson 1981), but stand susceptibility and extent of losses can be predicted (Amman and McGregor 1985).

All hazard-rating systems for determining stand susceptibility to MPB outbreak were developed in unmanaged lodgepole pine stands. Except for Amman and others (1977) and Safranyik and others (1974), these hazard-rating methods are based on measurement of tree vigor. The Amman and others (1977) and Safranyik and others (1974) hazard-rating systems are based on three major factors that affect mountain pine beetle survival -- climate, tree age, and tree size.

The Amman and others (1977) system (Table 1, Figure 1) gave good results on the Kootenai National Forest, Montana, Table 2. Elevation, average stand age, and diamter for lodgepole pine ≥ 13 cm dbh, as well as parameters used for other hazard-rating systems, are obtained during a standard stand examination. For stands, a systematic random or grid sample of 10 variable plots is recommended. For larger stands, 20 variable plots are suggested. A basal area factor giving 10 count trees per variable plot is usually sufficient. Age is obtained from increment cores taken at breast height from three trees nearest to plot centre that are 13 cm dbh or larger. Average stand diameter is determined from measurement of all lodgepole pine trees ≥ 13 cm dbh within each plot. Risk values are assigned to each of three factors - - climatic suitability, average tree age, and dbh. Greater than 50 percent mortality can occur in high-risk stands, 25 to 50 percent in moderate-risk stands, and <25 percent in low-risk stands (Amman and McGregor 1985).

Several methods of rating lodgepole pine stands for susceptibility to outbreak have been developed (Amman and others 1977; Berryman 1978; Crookston and others 1977; Mahoney 1978; Safranyik and others 1974; Schenk and others 1980; Waring and Pitman 1980; and Stuart 1984).

Crookston and others (1977) developed the simplest system which plots historical infestations on a map based on frequency and intensity of past infestatioms from which land managers can determine areas prone to MPB (McGregor and others 1981; Stuart 1984). Safranyik and others (1974) used weather to define hazard by climatic regions in British Columbia. Where climatic conditions were highly conducive to outbreaks, stand susceptibility was further evaluated using age and tree diameter (Safranyik 1975, 1978; Shrimpton 1975). Other hazard-rating systems have been based on the following parameters: habitat types; tree diameter and elevation (Roe and Amman 1970; McGregor 1978); phloem thickness and tree diamenter (Cole 1978; Cole and Cahill 1976); periodic growth ratio (Mahoney 1978); crown competition factor (Schenk and others 1980); tree vigour (Waring and Pitman 1980); and phloem thickness, tree vigour and MPB population dynamics (Berryman 1982). Amman and others

Table 1. Factors for rating lodgepole pine for the risk of mountain pine beetle infestation in Montana. By multiplying the following risk factors (1 = low; 2 = moderate, 3 = high) for elevation and latitude, average age, and average dbh, the stand's susceptibility classification is obtained; low - 1 to9; moderate = 12 to 18; high = 27.

	Low = 1	Moderate = 2	High= 3
Elevation-latitude	High	Moderate	Low
Average age (years)	<60	60-80	>80
Average diameter LPP 13 cm d.b.h.	<17.8 cm	17.8 - 20.3 20.3 cm	>20.3 cm

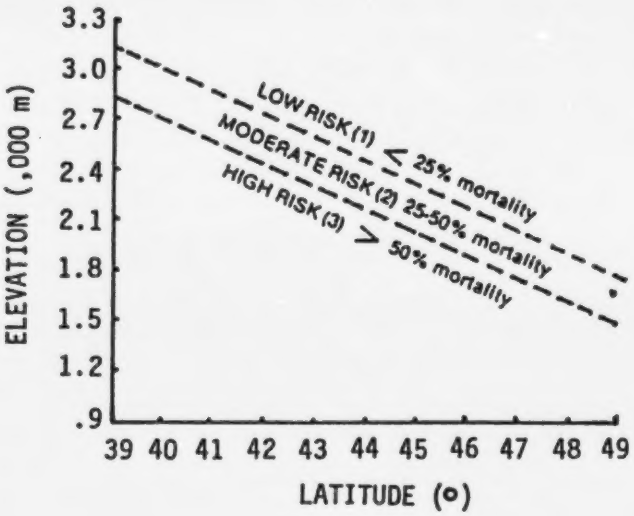


Figure 1. Risk of mountain pine beetle infestation in lodgepole pine can be defined by zones of elevation and latitude. Percent mortality is for trees 22 cm dbh and larger (Amman et al. 1977).

Table 2 Mountain pine beetle infestation in logepole pine stands,
Kootenai National Forest, Montana, USA

1974-1984

AREA INFESTED (ha)

Hazard	1975		1976		1977		1978		1979		1980		1981		1982		1983		1984	
Class	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Low	0	0	0	0	4	1	251	1	11	1	102	1	0	0	114	1	302	1	4800	13
Mod.	0	0	0	0	345	1	202	1	186	1	347	1	612	3	497	2	213	1	3365	17
High	2094	2	7199	6	4434	4	8393	7	12005	11	25306	22	29090	25	28985	25	22294	20	60453	53

(1977) developed an integrative hazard rating system with the following parameters; (1) climatic suitability of stand location for beetle survival; (2) average tree diameter ≥ 21 cm dbh; and, (3) average age of lodgelpole pine ≥ 13 cm dbh in the stand (Table 1, Figure 1). Stuart (1984) used quadratic mean diameter and number of rings in the last centimeter of radial growth at dbh to classify stands into appropriate categories (attacked vs. nonattacked).

After stands have been rated for beetle hazard, the next step is to determine the expected rate and amount of tree loss if a stand becomes infested. The probability of a tree becoming infested depends on the susceptibility of the tree, the length of the flight period, the size of the attacking beetle population, and environmental conditions of the stand (Cole and McGregor 1983).

Few hazard- or risk-rating systems addressed amount of loss. The method of Mahoney (1978) is based on periodic growth ratio (PGR) of annual radial increment.

$$\text{PGR} = \frac{\text{current 5-years' radial growth}}{\text{previous 5-years' radial growth}}$$

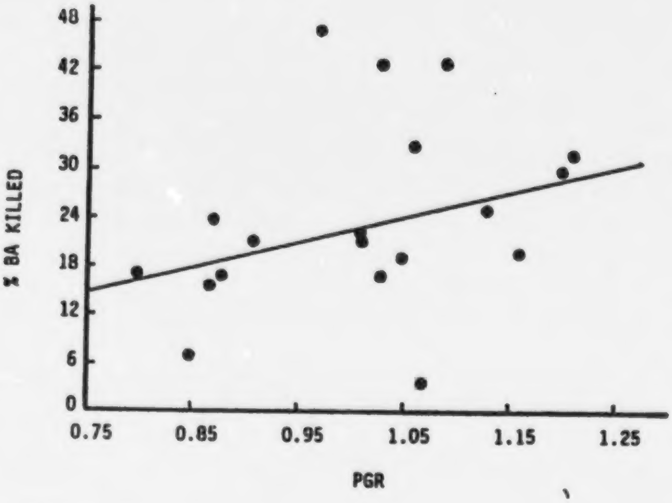
Stands having a PGR <0.9 are susceptible, whereas stands with PGR > 0.9 are resistent to MPB. Susceptible stands would suffer more than 10 percent mortaility, whereas resistant stands would have 10 percent tree mortality for trees 12.7 cm dbh and larger.

Data collected from stands on the Gallatin and Kootenai National Forests, Montana, in 1984 show that as PGR increased above 0.9, amount of lodgepole pine basal area killed increases. This same relationship held true for lodgepole pine trees ≥ 12.7 cm dbh and for trees ≥ 28.7 cm dbh (Figure 2).

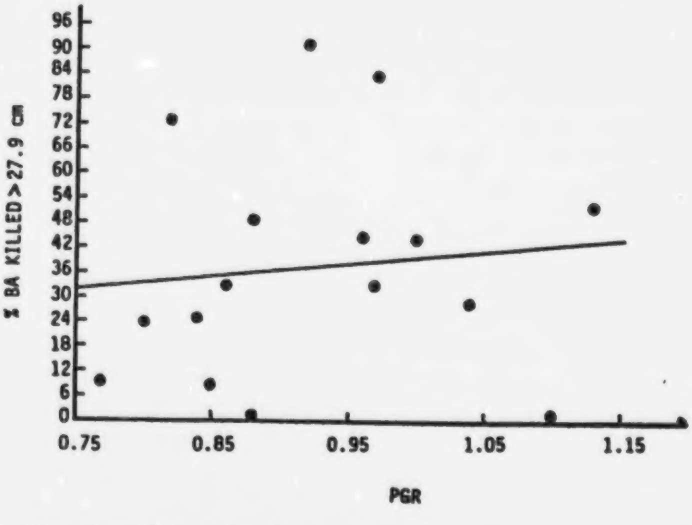
The method of Schenk and others (1980) uses crown competition factor (CCF) and proportion of lodgepole pine basal area in the stand to calculate stand hazard rating (SHR):

$$\text{SHR} = \text{CCF}\ \frac{(\text{Proportion of LPP BA})}{100}$$

An SHR of ≥1.0 indicates significant lodgepole pine mortality can be expected. Data from stands in Kootenai National Forest show that as SHR increased, the percent of stands basal area killed declined (Figure 3). Although these data are preliminary and regressions are not significant, it does show trends.

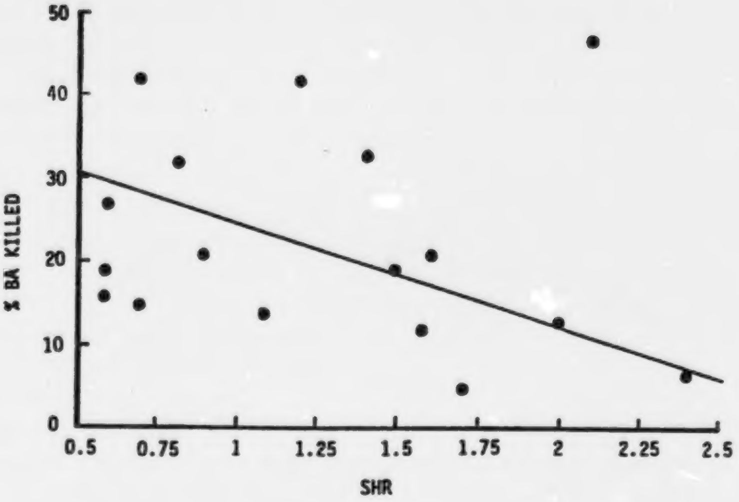


(a) Gallatin National Forest: Y = -7.68 + 31.179 * X

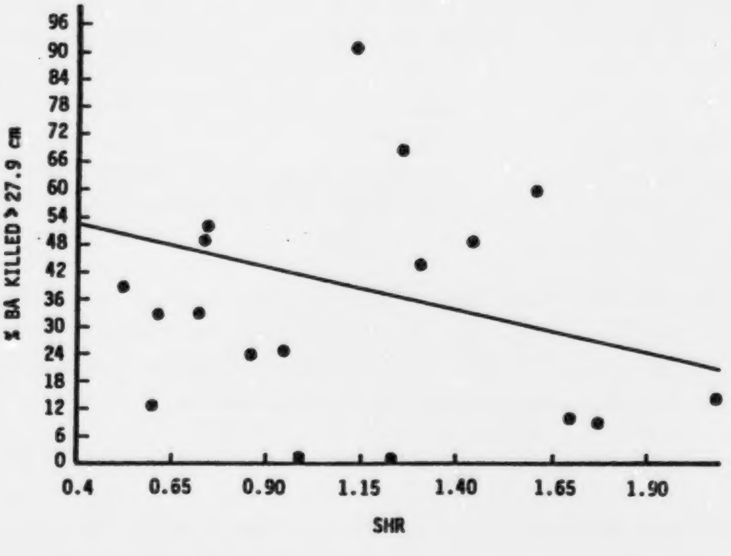


(b) Kootenai National Forest: Y = 10.46 + 29.84 * X

Figure 2. Percent basal area killed in relation to PGR.



(a) Percent total BA killed: Y = 34.155 + -7.885 * X



(b) Percent BA > 27.9 cm killed: Y = 51.938 + -13.786 * X

Figure 3. Percent basal area killed in relation to SHR.

Waring and Pitman (1980) didn't specify the amount of loss expected in stands of different susceptiblity. They stated that trees producing 50 gms of wood per meter^2 of foliage are highly susceptible, 51 to 100 gms moderately susceptible, and >100 gms highly resistant to beetle attack. Waring and Pitman (1980) stated only lodgepole pine with lower vigour indices are attacked and only those with very low vigour are killed by MPB (Amman 1983 unpublished data).

Data from the Gallatin and Kootenai National Forests follow essentially the same pattern that Waring and Pitman found, i.e., trees with high vigour are more resistant. However, in those stands where outbreaks have been in progress 3 years or less, MPB appears to be selecting and killing lodgepole pine of highest vigour first. Many of these trees have a vigour rating of more than 100 and should be resistent.

Berryman (1978) proposed the use of PGR/SHR as a measure of stand susceptibility. The percent of stand basal area contained in lodgepole pine trees having a phloem thickness > 2.5 mm is used as a measure of the potential to support MPB (Amman 1983). The probability of an outbreak decreases as percent of basal area in trees having 2.5 mm thick phloem decreases. Stands that contain less than 10 percent of the basal area in trees with ≥ 2.5 mm thick phloem have little or no chance of a beetle outbreak. Berryman further fits his data to a synoptic model which states low-hazard stands will have ≤10 percent of the basal area killed over a 7-year period, higher hazard stands will experience 11 to 40 percent of basal area mortality, and stands classed as extreme hazard will have ≥40 percent of the lodgepole pine basal area over a 7-year period.

Of the stands examined on the Gallatin and Kootenai National Forests, using PGR/SHR, only three of 27 were predicted to have an outbreak (Figure 4). Mortality ranged from 4 to 73 percent of the lodgepole pine basal area per acre. Of the stands that have sustained outbreaks over a 7-year period, three stands (1 percent) lost <10 percent of the lodgepole pine BA/AC, 20 stands (66 percent) lost 11 to 40 percent of the lodgepole pine BA/AC, and seven stands (23 percent) suffered >40 percent basal mortality.

Since tree mortality varies greatly within stands rated high hazard, the manager is not only concerned with which stands are most susceptible, but how many trees will he lose if the stand becomes infested, and over that time period?

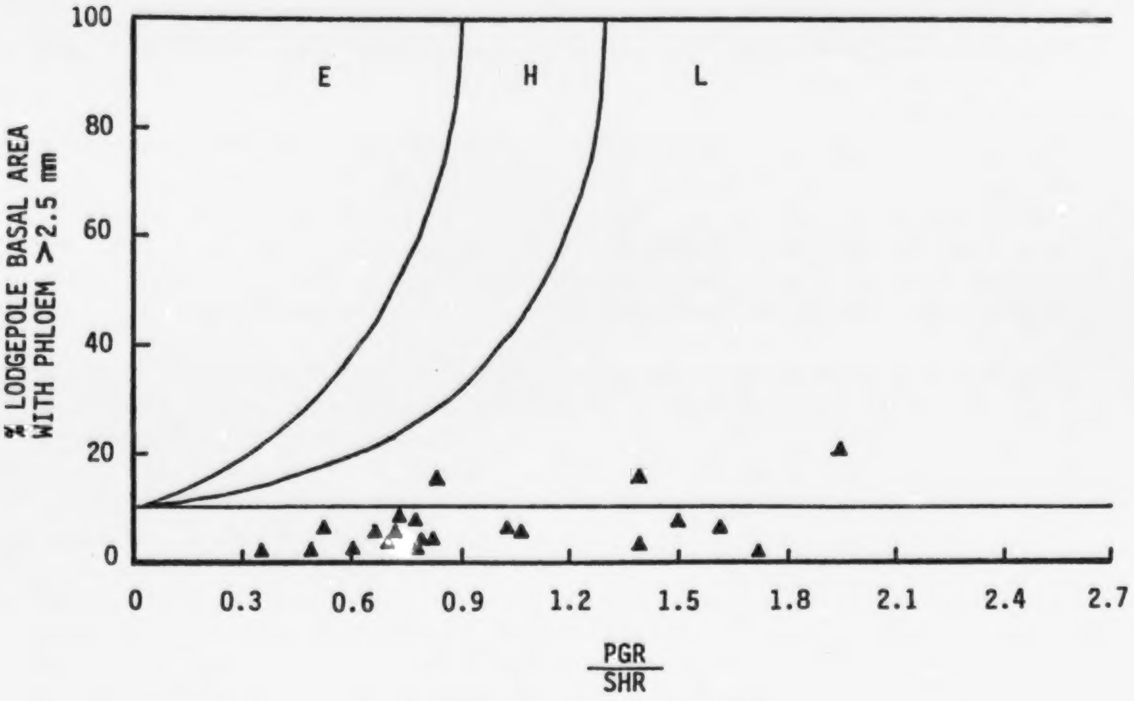


Figure 4. A fit of the synoptic model to data from 21 lodgepole pine stands on the Gallatin and Kootenai National Forests, Montana. E = Extreme; H = High; L = Low.

The probability of a tree or stand becoming infested depends on susceptibility of the trees within the stand, length of the beetle flight period, size of the attacking beetle population, and environmental conditions of the stand (Cole and McGregor 1983). A rate of loss model incorporating these factors was developed by Cole and McGregor (1983), and is based on the Reed and Frost Model (Abbey 1952).

The rate of loss model assumes optimum conditions for the beetle throughout the life of the epidemic; however, detrimental conditions can impede beetle populations and cause actual tree losses to be less than predicted. Although actual and predicted tree losses are usually similar for the larger diameter classes where epidemics begin, the model tends to overestimate losses in the smaller diameter classes when conditions are less than optimum for the beetle. This bias is not considered detrimental, but rather helpful since it allows examination of "worst-case" scenarios. Such examinations are made possible by looking at other measures of loss in addition to number of trees killed.

The rate of loss model has been integrated with the INDIDS model (Bousfield 1981) to estimate mortality trends for already infested stands and to obtain loss estimates in cubic and board foot volume for green stands if they become infested. The INDIDS model is used to analyze forest insect and disease survey data collected from variable or fixed plots. It summarizes by tree species, size class, and damage class, the loss to be expected in number of trees, basal area, and volume killed per acre.

Several silviculturists on Ranger Districts have made additional use of the INDIDS-COle MPB-Lodgepole Pine Loss Model. Some of the more important uses of the MPB-Lodgepole Pine Mortality Prediction system are:

1. Identifying Several Areas for District Timber Sale Program Based on Predicted Lodgepole Pine Mortality.

   It totals for each subcompartment and offers the best starting point. The subcompartments with the greatest predicted lodgepole pine mortality are usually highest priority for harvest. However, management objectives other than timber may modify the priorities.

2. Identifying Individual or Groups of Stands as Potential Cutting Units Bases on Predicted Mortality Losses.

   Individual stand information can be produced for any of the subcompartments selected. These include lists of individual stand information in order of stand number; sorting of individual stands into high (120 m^3/ha loss), moderate (60-108 m^3/ha loss), and low risk (24-48 m^3/ha loss). This sorting is useful when the decision may have been already made to remove certain categories to timber, ex. high risk. It is also useful in showing the nature of the stands and where they are located. For example, where is the highest concentration of high-risk stands?

3. Summarizes Selected Stands into Timber Sale Alternatives.

Several groups of stands are usually established as alternatives for further evaluation. It allows the listing of separate stands and displays totals for each group. These totals can be compared to select the most desirable alternative. Where stand and unit sizes differ, the stand size in the data inventory can be temporarily changed and then changed back after an evaluation has been made. These reports give total volume available for each alternative, as well as predicted mortality and ECA effect.

4. Equivalent Clearcut Acre (ECA) Effect.

The ECA computation produces a value equating the hydrologic effects of the predicted mortality with the effects of clearcutting. The basic equation uses basal area reduction and assumes that any reduction less than 20 percent will have no effect. At the other extreme, there will be a 70 percent effect where 100 percent of the merchantable trees are killed. The remaining 30 percent is due to sub-merchantable trees and other ground cover. These data are available in predicting the effects of mortality even if no cutting is done and allows you to examine alternatives with least hydrologic impacts. It has shown us that several drainages will be significantly over hydrologic limits just from lodgepole mortality.

5. Residual Stand Description.

A description of the post epidemic stand is useful for:

a. will the stand have adequate post-epidemc stocking to continue to manage or should it be regenerated;

b. will the stand continue to provide valuable widlife habitat; and,

c. will the post-epidemic stand meet Visual Quality Objectives (Beckley personal communication 1975)?

The Amman and others model is useful for classifying unmanaged stands according to high, moderate, and low classes of susceptibility. The rate of loss model provides a method for predicting which of the high-hazard stands will sustain the greatest amount of loss over time.

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MOUNTAIN PINE BEETLE PROBLEMS IN ALBERTA (ABSTRACT)

R. Miyagawa[1]

The present mountain pine beetle infestation was first noticed in 1977 when a number of small infested areas were discovered in Waterton National Park and the adjacent provincial forest. No immediate action was taken and by 1979 the spread was severe enough to indicate that a major epidemic was beginning. Thus, in 1980, the Alberta Forest Service initiated action to limit the beetle spread. The affected area was split into a beetle control zone and infested salvage zone.

The objectives of the control zone were to:

1. limit the northward spread of the beetles; and,
2. maintain the pine stands within this zone.

All infested trees in this area were treated individually. Treatment method included felling and either salvaging, debarking or burning the infested logs. Pheromone baits were also used to aid in the control program. Since the inception of this program, the Province has spent five million dollars to treat eighty thousand trees. Thus far, our objectives have been achieved. The beetles' northward spread has been limited; as well, we have maintained the majority of the high and moderate beetle hazard rated stands within this zone.

The salvage zone included all areas where the beetle infestation had gone beyond any control action. The objective of the programs in the salvage zones were to:

1. salvage as many dead infested trees as possible;
2. decrease the beetle population in this area;
3. minimize the creation of future fire hazard; and,
4. enable the forest managers to regenerate and reclaim the affected area as soon as possible.

Incentives were given to logging operators for this salvage program. Landscape logging methods were used to minimize the visual effect of clear-cutting programs. Environmental and special interest considerations were also included in the process. Timing of log movements was controlled to minimize the spread of beetles. Salvage operations have been almost completed. Over four thousand hectares yielded approximately one hundred and thirty million board feet of salvage lumber.

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APPLICATION AND FEASIBILITY OF ALTERNATIVE CONTROL STATEGIES

L. Safranyik[1]

Introduction

Over the past 80 years a variety of methods have been developed and used for reducing losses from the mountain pine beetle (MPB) in western North America. Most of the earlier control programs involved single tree treatments, such as felling and burning or spraying infested trees with bark-penetrating insecticides. During the past three decades, as lodgepole pine became increasingly valuable as a commercial species, sanitation logging was used more frequently in operational control programs. With some notable exceptions, the earlier direct control programs were not successful in suppressing outbreaks or reducing large scale mortality. Either direct control did not work or it was being improperly applied (Whitney *et al*. 1978), thus, the usefulness of direct control as a strategy was seriously questioned.

Advances during the past 20 years in our understanding of beetle/tree/stand interactions led to a preventive management strategy, based on silvicultural practices, and redevelopment of the concept of direct control (McMullen *et al*. 1985). The purpose of this paper is to briefly review the role of direct control in reducing losses from MPB, the requirements for an effective direct control program, and the operational feasibility of the control methods.

Preventive Stand Management vs. Direct Control

Reduction of losses from MPB are based on two general approaches (Safrayik 1982): preventive management and direct control. Preventive stand management involves long-term planning and silviculture practices aimed at reducing stand susceptibility. Some of these practices, such as removal of trees of susceptible size by selective logging, can be applied effectively in the early stages of an infestation (Cahill 1978, Cole *et al*. 1983), while others, such as regeneration of logepole pine in small blocks to create mosaics of stands of different ages, require long-term planning (Cole 1978, Roe and Amman 1970, Safranyik *et al*. 1974, Schmidt 1982). However, extensive susceptible stands are present today and, in spite of the best efforts of intensive management, will on occasion be present in the future and will require the application of direct control.

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The objective of direct control is to reduce beetle numbers to levels at which they do not cause economically important damage or to reduce population expansion to provide time for the orderly harvest of infested and nearby susceptible stands. Direct control is expensive in time, effort, and resources and does not treat the underlying cause of outbreaks which is stand susceptibility. Hence, in spite of its long history there is no general agreement among scientists and foresters regarding its effectiveness in reducing losses. Most of the early suppression programs were directed against large outbreaks (Klein 1978, Whitney _et al_. 1978) and, at best, only reduced the rates of tree mortality (Amman and Baker 1972). Earlier successful control programs (e.g., Hopping 1946) and recent theoretical work (Berryman 1978), field experiments (Dyer 1978, McMullen 1980, Borden _et al_. 1983) and operational programs in B.C. and Alberta indicate that direct control can be a sound strategy provided these requirements are met:

(1) the initial treatment over the entire area to be protected must be completed within one or two seasons;

(2) control work must continue as long as there is evidence of beetle activity;

(3) all relevant tactics should be applied in a co-ordinated manner when possible; and,

(4) success is dependent on the thoroughness in all aspects of treatment application and of surveillance.

When all of these criteria are met, and provided that the control area is relatively isolated from other infestations, there is a good chance that an infestation can be suppressed. Undoubtedly, the chance of successful control will be higher in areas where adverse weather conditions can severely reduce beetle survival. When any of the above criteria cannot be met, the most realistic expectation from direct control work is a reduction in the rates of increase in beetle population and damage level.

Application and Feasibility of Direct Control Methods

For the purpose of direct control, infestations can be viewed in much the same manner as fire: the most practical and economically feasible approach is to act early and extinguish the fire when it is small. The same holds true for MPB control. Early action also increases the chance of success of the control operation.

In practice, it is often prohibitive to treat all infestations. Therefore, stands should be priorized according to their socio-economic value and risk of stand depletion from MPB in the event of an outbreak (stand ratings for MPB losses were discussed earlier by Mr. McGregor in these proceedings). Control action should be concentrated in those stands that have the highest management priorities, or nearby stands if the beetle is threatening from these. The locations, numbers, and sizes of infestations selected for control will depend, to a large extent, on the resources available to the manager.

The various direct control methods discussed by the other panel members are all biologically effective. Each method has its advantages and disadvantages depending upon the ease and timing of application and operational requirements. They can be used singly or in combination throughout the year prior to emergence of the beetles.

Sanitation logging, in which infested trees containing living beetles and uninfested susceptible trees are removed from the stand (usually by block clearcuts) and utilized, is the most commonly used and frequently the most cost-effective method of direct control in B.C. However, sanitation logging may be hindered by poor or non-existant road access, problems of ownership, delays in issuing of cutting permits, poor timber markets, hauling restrictions and other operational problems. Also, sanitation logging is generally not suitable for treating scattered infestations, especially on rough terrain.

Single tree treatments usually do not yield any salvage value and it is difficult to treat large infestations using these methods. However, these treatments are more suitable than salvage logging for treating isolated spot infestations, especially in remote locations, and for "mopping up" infestations following sanitation logging. For these reasons, sanitation logging and single tree treatments should be used in combination in most suppression programs. In selecting single tree treatments, proper timing and application are often much more important considerations than the relative costs. For example, treating infested trees properly with MSMA, one of the least costly treatments, a month after attack would probably cause little or no MPB mortality.

Baiting of uninfested trees with semiochemicals is highly effective in inducing beetles to attack these and nearby trees (Borden et al. 1983a, 1983b). Hence, baiting can greatly increase both the biological and cost-effectiveness of direct control programs. In combination with sanitation logging, semiochemicals offer promise for reducing dispersal of beetles from larger infestations. However, the strategy of using semiochemicals for this purpose needs more development.

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QUESTIONS

QUESTION: Why are we not doing more work on biological control?

LES SAFRANYIK: As Dr. Schmitz indicated previously, invariably the abundance of any natural pedator, parasite, or disease is so low initially that researchers figured they didn't contribute much to affecting the course of the epidemic. Secondly, when more detailed studies were done, they found that the fluctuations in abundance of these organisms did not much relate to the changes in the abundance of the bark beetle. Hence the general concept developed that natural control, biological control is, relatively speaking, ineffective in suppressing bark beetle infestations.

Now the philosophy is that either enhancement of the populations of local predators and parasites, or introduction of exotic species might help suppress local spot infestations. The hope of using this kind of an approach for suppressing large infestations is rather unreasonable. However, there is the hope that injecting some exotic organism, be it an insect or disease, into bark beetle populations at the endemic state, might then regulate the density of them and perhaps we'll gain by reducing the frequency of infestation in some cases.

JOHN BORDEN: My basic philosophy of pest management, as I explained in talking about semiochemicals, is to put your research efforts on things that have eventual possibilities of success. Meanwhile, focus your management efforts on things that have the most probability of immediate success. The main problem with bark beetles is that they're inside of the tree, and the problem is trying to reach every one of them.

Meanwhile, some of the things we're doing are really types of biological controls. Silvicultural controls are really cultural controls. You're manipulating a stand so that the trees are vigourous, so you're using a natural phenomenon, the physiological vigour of a tree, to beetle proof a stand. Semiochemicals are classed in many cases as biological controls, and I think they are very useful. Fire, I think, should be considered a natural agent that we manipulate in the same way that you can manipulate an organism. And if you look at natural controls instead of biological controls, I think that fire is a logical agent to use in certain instances.

QUESTION: You've mentioned that single tree treatment seemed to be low priority, in the states. I was just wondering if you could explain the reason this decision came about.

MARK McGREGOR: There could be a number of reasons it didn't work. In the sixties for about an eight year period they were felling and burning trees all winter in Grand Teton Forest, and Grand Teton National Park, and in other areas in other national forests. We were killing beetles. We did nothing to change stand susceptibility, and the beetle moved through those stands just as if nothing had been done. A lot of these stands were adjacent to the Teton Wilderness Area and portions of Grand Teton National Park where we could do nothing, and next to Yellowstone National Park. These areas had tremendous beetle populations. The areas acted as reservoirs, replacing the beetles that had been killed, and negating our efforts.

JOHN BORDEN: I think if you've got three spots in three thousand hectares, and you're not next to a wilderness area, you should do single tree disposal. Maybe there's a cut off point where you get so many spots in that area that the prescription changes and it becomes a clearcut. If you're going to do single tree disposal on a vast, vast area, and a vast, vast infestation is building up over a wide front, it's at best a holding action. And possibly is totally ineffective.

MARK McGREGOR: It may be a holding action, but you may, in many instances, quit attacking the epidemic of mountain pine beetle and attack the epidemic of lodgepole pine, because as long as you've got that susceptible host, you're going to have epidemic beetle populations.

PANEL IV - ECONOMICS

INTRODUCTORY REMARKS

J. Doug Little[1]

You have had an opportunity to hear a panel on the biology of the mountain pine beetle; you have had an opportunity to share in the deliberations on methods of detection; and you have examined options for management which would assist in control of the pest. All these matters are important if we intend to mount a successful program of forest resource management.

However, this discussion is not worth much unless it can be translated into economically feasible actions designed to control the incidence of beetles in forests as we progress towards acceptable resource management.

Your final panel will examine the economics of beetle management. In other words, if we understand the biology of the beast, know where it is attacking, and where it is likely to attack, know what management options are available for control, then how can all this knowledge be brought together in a way to accomplish the objectives of controlling insects to prevent significant forest and economic losses?

Effective control of beetle edpidemics is important - just as important as fighting forest fires. However, the legislation concerning pest management in B.C. leaves a lot to be desired. When one examines the insect control section of the Forest Act (Section 125-127) and the fire control section (Section 120-124), it is apparent that compensation for fighting fires is readily available, whereas compensation for controlling insects is not. Yet insects destroy forests as surely as fire does. A person doing all he can to control a fire "shall" be compensated (Section 122) whereas one who is obliged to control insects "may" be compensated (Section 127). Also, there "may" be compensation for insect control under Section 88 of the Act. Note that I say "may" be compensated, not "shall", for insect control. Furthermore, there are eleven pages of administrative policy and procedure to be followed by Ministry personnel in developing a comprehensive program of insect management. However, there does not appear to be any declaration that there will be any economic analysis or cost benefit studies performed before programs are introduced. If this is a fact, how many are aware of it?

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[1] Mr. J.D. Little, Senior Vice-President, Northwood Pulp and Timber Ltd.

It is obvious that both industry and government have a special interest to ensure that timely, cost effective insect control programs are maintained with due regard for the macro-economics of forestry in B.C. Having been intimately involved in the forest scene in B.C. for many years, my observation is that there are no apparent well developed action plans, nor is there any information available relative to financial implications if government and industry were to mount such programs.

Harvesting of insect-killed timber has been a main item on the menu of forest companies for many years and there appears to be no let up in sight. Perhaps through this panel a better understanding can be gained on the economic problems involved and how all parties can work together to ensure that scarce dollars spent on control are used effectively.

ECONOMICS OF BEETLE MANAGEMENT
ROLES, RESPONSIBILITIES AND FUNDING

M.J. Wilkins[1]

My role on the panel is to define the functions and responsibilities of both the Forest Service and Industry for mountain pine beetle (MPB) management and secondly to review the various funding mechanisms by which this can be achieved.

In dealing first with the functions (roles) and responsibilities, I would like to describe the statutory and contractual requirements and then make reference as to how these are implemented.

Section 4 of the Ministry of Forests Act defines the purposes and functions of the Forest Service. More specifically in subsection 4(b) it directs the Forest Service to "manage, protect and conserve the forest and range resources of the Crown ...."

Although Section 4 assigns purposes and functions specifically to the Forest Service, given the partnership type of management concept we have in this Province, I consider the contents of Section 4 to apply equally to Industry.

The Forest Act, Section 12(e) requires the holder of a Forest Licence to prepare a Management and Working Plan (M & WP). Condition 3.05 of the Forest Licence document requires the licensee to include in the M & WP information concerning the protection of the forest resource.

Section 28(d)(iii) of the Forest Act requires the holder of a Tree Farm Licence (TFL) to prepare a M & WP containing proposals to protect the forest from damage by fire, insects and disease. This provision is confirmed in the TFL document under condition 2.06(c). In addition, the new TFL Subsidiary (Partnership) Agreement requires the licensee to take effective pest management action while requiring the Forest Service to co-ordinate and provide consultative services as required, and to audit licensee's performance.

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[1] M.J. Wilkins, Regional Manager, Prince George Forest Region, B.C. Ministry of Forests.

Section 125 of the Forest Act provides in part that the Regional Manager may require any holder of an agreement to take appropriate measures to control or dispose of insects.

Condition 3.03(a) of a Forest Licence provides that the licensee may be required by the Regional Manager to amend a M & WP to provide for management of timber infested by insects.

In like manner the Chief Forester may require amendment of a TFL M & WP when timber is infested by insects.

The last Section of the Forest Act to which I would like to refer is Section 127. It permits the Regional Manager to enter into cost sharing agreements for the control of insects or disease on forest land and is intended to allow the Forest Service and other agencies, such as Regional Districts, to jointly manage and cost share infestations on areas under their respective jurisdictions.

I have dealt specifically with the statutory and contractual requirements of the major tenures under the Forest Act, i.e. Forest Licence and TFL. There are similar if perhaps less onerous requirements for holders of Timber Sale Licences and Woodlot licences.

How then do we deal with and implement these statutory and contractual requirements?

I mentioned earlier the partnership philosophy between the Forest Service and Industry. The key implementation vehicle quite obviously is the M & WP and Development Plans subject to it.

In the case of Forest Licences, the responsibility of the licensee clearly extends over the planning areas approved for the licensee by the Regional Manager within the Timber Supply Area (TSA).

In addition, I see a significant role for the TSA Steering Committee in the development of plans to control and/or harvest beetle infested stands as they occur within a TSA.

The implementation of pest management strategies on a TFL are more easily defined given the "fixed land base" type of tenure. There should, of course, be continued liaison with the Forest Service and any steering committees of adjacent TSA's.

The matter of funding for pest management activities is a bit of a "dog's breakfast" and I will try to crystalize and summarize it as best I can. Some general observations first.

Funding for pest management over the years has not only been fragmented but also less than adequate. The recently released Forest and Range Resource Analysis contains a very appropriate comment on page 37 of the Summary Report and I quote:

> "Cost-effective solutions to many pest outbreaks lie in early detection and in the ability to initiate rapid aggressive action; before the problem escalates beyond control. But the present budgeting system does not permit such emergency action: time-consuming proposals must be made to various levels of government, which prohibits quick and economical solutions. Provisions for drawing on emergency funds would enable the Protection Program to cope with pest outbreaks before they get out of hand."

I consider this a very valid comment. It seems to me that the authors of the statement are suggesting that pest management activities funded in a similar fashion to fire suppression would go a long way towards permitting the Forest Service and Industry to take early, decisive action.

Coming back to the real world - how do we at present fund MPB management

There are four basic management functions and four basic funding mechanisms:

Function

Planning
Aerial and Ground Surveys
Control: Single Tree Disposal/Harvesting
Monitoring

Funding

F.S. budget
F.S. special warrant
Section 88
Stumpage Appraisal

Let me try and tie these together.

The planning function is obviously one that is the responsibility of both the Industry and the Forest Service. Preparation of M & WP and pest management plans specific to a licensee's planning areas are obviously the responsibility of the licensee with funding provided for through the Overhead/Supervision allowance in the Stumpage Appraisal. Forest Service responsibility for planning lies in areas outside of TFL's and licensee planning areas and is funded from budgeted funds.

The aerial survey, is a function for which, with the exception of TFL's, the Forest Service with assistance from the Canadian Forestry Service, takes responsibility. The survey is conducted annually, generally in the late summer to early fall with summaries and maps made available to to the Industry. Expenditures are covered by budgeted funds.

The ground survey/detection function, or probing if you like, again is a split responsibility with licensees responsible for this activity within their planning areas and the Forest Service responsible for all other areas in the TSA. Expenditures for licensee probing qualify under Section 88. Forest Service funding may be available either through budgeted funds or special warrant.

The ground control function covers widely disparate activities using trap tree techniques such as baiting trees with pheromones (semiochemicals), falling and burning, falling and spraying, and harvesting.

Responsibilities for trap tree activities and baiting and/or treating individual trees are easily definable. Licensees are responsible within their planning areas with costs reimbursed under Section 88. For areas outside of planning areas, the Forest Service accepts responsibility with funding provided either from the annual budget or special warrant.

Responsibilities and related funding mechanisms are less easily definable under the harvesting activity. Minor, localized infestations where the prescribed control mechanism is harvesting within a licensee's planning area obviously fall under the responsibility of the licensee. Costs associated with the "operational" harvesting of beetle infested timber are properly amortized in the stumpage appraisal of the appropriate cutting permits.

Where infestations became major and widespread, encompassing two or more licensee's planning areas, the co-ordinating responsibility rightfully lies with the TSA Steering Committee and the Forest Service. Involvement of the Small Business program in a significant way may also prove to be desirable.

In this circumstance, monies available under the Small Business Program Fund may become available for access development as well as funding that the Forest Service may obtain under special warrant.

In summary may I generalize by saying that the Forest Act and tenure provisions delegate the responsibility for pest management activities to both the Forest Service and Industry.

The licensee's responsibility generally lies within the planning areas defined in the TSA plan or TFL area, while TSA areas not covered by licensee planning areas are the responsibility of the Forest Service.

Amortization of licensee costs is subject to Section 88 and stumpage appraisal policies; Forest Service expenditures are subject to available budgeted funds and special warrants.

The success of any pest management program must lie in a co-ordinated partnership approach which maximizes liaison between the Forest Service and Industry through groups such as TSA Steering Committees.

COSTS AND BENEFITS OF BEETLE MANAGEMENT FROM THE PRIVATE SECTOR VIEWPOINT

Allan Dupilka[1]

My topic is the cost and benefits of beetle management from the private sector viewpoint. This is an extremely important issue for those areas heading for a potential mountain pine beetle (MPB) epidemic, namely the Quesnel Timber Supply Area (TSA), the Prince George TSA, the Lakes, Morice, Bulkley and possibly the MacKenzie TSA's. Secondly, I would like to relate beetle management experiences that we, as a company, have gone through in the Central Interior of B.C. and offer some suggestions based on hindsight.

First of all I'd like to discuss costs and benefits of beetle management.

Benefits are easy - stop the projected or active beetle attack and you can continue to plan forest management as you have always done with nice things like sustained yield and AAC's, normal forest, planned harvesting and silvicultural treatments, continuous revenue from the forests.

Of course, for industry, on the surface, there sometimes appears to be short-term benefits of a beetle attack:

a) beetles can remove the arbitrary regulations which restrict cut block size when beetles move into your reserve strips. This makes roads more cost efficient;

b) sometimes beetles move into good wood that you wanted to get your hands on for many years; and,

c) sometimes you don't have any planning or road costs at all because the beetles tell you where you're going.

Don't count on these and try to carry a box of mountain pine beetles in your back pocket next time you head for your favourite patch of timber.

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[1] Allan Dupilka, Chief Forester, West Fraser Mills Ltd., Quesnel, B.C.

Let the beetles go ahead of you and you get to the cost side of the equation. Cost of beetle management is where the problem really comes. There are two general areas of cost. Number one, the cost to everyone if beetles are not controlled. Number two, the actual costs involved in beetle management activities.

First of all, I'll cover the costs to everyone if the beetles are not controlled:

1. The first thing that appears obvious to me is that once you have a large beetle epidemic such as occurred in the East Kootenays, and in the Williams Lake TSA, the only known way of reducing the attack is the eventual depletion of the host pine. If you can't log it fast enough, the beetles will eventually get the rest. The hardest figures to come from any beetle report is the actual volume lost from beetle attack. We can get volumes killed but not the volumes lost. For forest management purposes we must also know what volume is being lost annually.

2. Let's wildly forecast the northern beetle movement from the Williams Lake TSA where the mountain pine beetle is totally out of control into the Quesnel TSA and in the Prince George/Prince Rupert regions. This problem is compounded with extensive spot infestations throughout the interior Prince Rupert Forest Region. The northern operators feel comfortable right now, but you should look at the size of the explosion in 1984 in the Williams Lake TSA and its rate of spread from there into the Quesnel TSA, and it's easy to project that the Prince George and Prince Rupert Regions will have this problem in a year or two, if the mountain pine beetle cannot be stopped.

    a) The Williams Lake TSA has 80 million m^3 of pine in areas contributing to the AAC or 43% of the TSA volume is pine. This volume is primarily located west of the Fraser River.

    b) In 1984, these western blocks had 16 million m^3 under attack primarily by the mountain pine beetle. In addition 10 million m^3 are under attack in the far west blocks that do not even contribute to the AAC.

c) 17% of the net volume in the western blocks is under attack or a 70% increase from 1983. This is a 300% increase from pre-1982. At this rate, by 1988-89 all pine west of Williams Lake could be gone regardless of logging control.

d) For logging control, Williams Lake has an AAC of roughly 2.5 million m^3 and a mill capacity of 3.5 million m^3 or roughly one-fifth of the volume that is presently under attack. If we assume very conservatively that half the pine volume cannot be utilized before it is lost, then the lost benefits are 20 million m^3 of economic value or a $4 billion economic loss will occur to this country in the next five years in the Williams Lake TSA alone.

3. a) These nippers breed very well and are expanding northward. In the adjoining Quesnel TSA, there is a net volume of 52 million m^3 of pine in the western portion of the TSA.

   The MPB is currently spreading rapidly through this area from the south.

   The Ministry of Forests predict that if present attack continues unabated, 80% of the available pine in the Quesnel TSA will be killed by 1992.

   Projected losses from unsalvaged material could be 30 million m^3 times $200/$m^3$ or a $6 billion economic loss in the next eight years.

4. a) In the Prince George West, MacKenzie, Lakes, Morice and Bulkley TSA's, if the trend continues and the beetle continues to move north, the potential loss, if only 25% of the pine is unrecovered, could exceed $20 billion of economic loss.

   This projected total lost for all these areas is in excess of $30 billion in economic loss of financial contribution to the B.C. economy in the next 10 to 15 years.

This economic loss is only the dollar effect on the future economy. The economic structure of the Central Interior must also be considered.

If the forecast is realistic, visualize the total Central Interior potential after the pine is gone. This relates to a 35% drop in production in the central interior, 35% less mills, 35% less work force, 35% less income generated.

Let's go back to the William Lake TSA example for a moment. 43% of that TSA volume and, simplistically, 43% of AAC is pine that is forecast to be gone by 1988. In theory, by 1988, decisions will be made on the economy of the Williams Lake area, as almost half the mature volume will be gone.

There are political questions which must be answered:

a) Does this mean half the mills will be shut down or all the mills will go to 50% production levels;

b) If you keep the economy at status quo, how many years of mature timber is available to maintain the AAC; and,

c) If you have 40 years of mature timber left, can we manipulate the land and its immature forest crop through forest management to prevent any fall-down effects?

These are the possibilities. The next item is "what is the actual cost involved in beetle management"?

These costs are costs to industry and government that must be considered to prevent the forecast from happening.

I Industry's side of the picture

Beetles don't operate under a controlled plan and I would like to state the things that often do happen that create epidemics.

1) Cost factors that prevent proper beetle management -

a) Haul Costs

In order to stop a beetle attack, the road costs to access the area may be too high for industry to operate. Industry can operate at break-even levels, but who will finance major, continuous losses?

This was the scenario which resulted in the Chilcotin MPB epidemic.

b) Mill Design

A mill is designed to handle its projected future wood supply. If this supply changes because beetle logging must occur in larger or smaller sizes of wood, the mill could be faced with a major problem. It may not be able to economically mill the new size of trees with the old equipment. If that mill cannot financially change its equipment, then it cannot help to eliminate the beetle wood and will be forced to log standing green wood just to stay alive.

c) Market Value

Increases in the market value allows much more flexibility before the mills reach a loss position that is intolerable. But unfortunately, industry has faced a dismal, near break-even market since 1979.

d) Market Volume

If the above three points are acceptable cost-wise, there is still a problem of major over-cutting to combat the beetle situation because the present marketplace is already in an oversupply situation and cannot absorb any more lumber. Certainly our friends across the border want us to cut back production and not increase our production.

II Cost factors in beetle logging

a) Unplanned road development

I mentioned earlier the case of beetle activity in existing reserve blocks and the effect of reduced road costs. These cases are often experienced under low level of infestations. Very often, the danger of beetle epidemic is largest in unaccessed stands and the attack is moderate to heavy before action is taken. These unplanned roads are expensive to construct as they cannot utilize the best weather conditions and trucking costs are high because of green, unset, and rough roads.

b) Wood Quality

i) If beetle stands are not logged early in the green attack stage, wood quality quickly deteriorates and will make the log not usable for lumber production. Checking and moisture level differences between green and dry wood create major problems in sawing and kiln drying and eventual lost grade. The grade may be quickly lowered to a point where the stand is uneconomic to harvest.

ii) Another major threat is loss of markets in Pacific Rim countries due to the above grade problems and particularly the occurrence of blue stain which is not readily accepted in this market. Numerous occasions have occurred within the last couple of years, of losses of contracted lumber due to blue stain and grade problems in this market.

iii) Increased logging costs often occur, where the logger's equipment is not designed for the size of wood that has been attacked. Most of these can be alleviated by quick action and co-operation among industry and the Ministry of Forests.

iv) Section 88 Funding. Lack of adequate funding levels and Section 88 credit balances reduce the desirability of this method for funding MPB control actions.

SUGGESTIONS FOR SUCCESS BASED ON EXPERIENCE

"Some people may not like these ideas and they feel they can win a few battles on their own, but the danger and cost of losing the war is too great".

I. Everyone in charge must realize that the only way to stop the beetles is a total understanding of the problem and a willingness to work together. No area of forest management requires this co-operation more than beetle management. Industry has the milling capacity to remove the pest and governments must develop a policy to allow the program to work. Who in this room is prepared to take the responsibility for a $30 billion loss? Have you already started blaming someone else? I tell you, we are in this together.

1) Detection and initial action

a) Interest area management or land based tenures is critical for industry. Long term interest area over a land base gives industry the incentive to protect the forest resource even at a loss in order to protect the long term supply. Tell me of one industry person in this room who would alone sustain a large cash loss to protect the resource when he knows that his neighbour can go and move into his low cost wood area once he has the beetles under control. TSA's and loss of interest areas create a situation where everyone is willing to be responsible for the low cost beetle wood and no-one is responsible for the loss position wood.

b) Let history show you. Move fast on any beetle sign. As I said earlier, let's learn from hindsight and not make the same mistake again. I'll give a few actual cases of what I consider poor beetle management:

   i) A massive spruce beetle epidemic occurred because the Ministry of Forests would not issue a cutting permit for two years after the initial attack occurred, because of the concern that the company wanted only high quality wood;

   ii) In 1978, some companies applied for ten year sales for around 500,000 m^3 out of the Chilko PSYU at the time the MPB was first spreading out of the Kleena Kleene Valley into the Chilcotin. This sale was denied because they were considered uneconomical and that small business could handle the problem. The timber is now basically all lost.

c) Examples are also known of industry which has convinced the Ministry of Forests that they could handle the beetle outbreak. This did not occur and by the time the situation had been recognized, another massive spruce beetle outbreak had occurred.

I know of as many or more correct decisions made, but let's not get complacent.

We must realize that these are sneaky and quiet little pests and that their potential numbers are devastating. Learn to throw all the rules to the wind and get on them fast.

d) Incentives

There is always a reluctance to allow lower stumpage rates, relax utilization, lower road standards, cruise-based sales, etc. to address beetle attack until absolutely necessary. The absolutely necessary time often comes when it is too late to do anything and the wood is lost and beetle populations have dramatically increased.

e) Tenure and AAC

There is also reluctance to give additional long term tenure on potential beetle epidemic areas and enlarge the existing AAC. We sit on an explosive situation in the Central Interior where a large volume of mature pine and spruce is ripe for a complete wipe-out by bark beetles. The Ministry of Forests cannot wait until the resource has only a few years left and expect industry to increase milling capacity to utilize this resource. The current economic situation allows only the most efficient and cost effective mill to survive and no-one can install a new sawmill at $10 to $30 million and write the cost off in 4 years. We must carefully weigh yearly the beetle potential and be prepared to increase AAC if the situation looks explosive. Once it's here, it's too late. If major road programs must be undertaken to access the beetle, we may also be too late. The forest land base is flexible enough to correct planned over cutting or other past decisions, but it cannot cope fast enough to handle epidemic beetle losses and the subsequent loss of land base.

f) Intensive Forestry

Our best future is in the managing of the land base better and moving the younger stock ahead. We can afford to liquidate the mature if we increase the growth in the immature. Improved vigour and growth in young stands through immediate re-stocking control, eliminating brush competition, and fertilization have proven to be a detriment to beetle attack. We must let government know what is happening and the potential effect and put money back into the forest before everything is lost. I realize it is difficult getting people to pull out the fire hose if they can't see the house burning, but the potential is worse than our present backlog reforestation requirements.

g) Research

I get concerned when people tell me we presently know everything there is to know about the beetles, and there is no control. I have also been told by high level forest funding people that if more money is required for biological control we must show that the beetle is out of control. Where have these people been? I feel we must infuse millions of dollars if necessary into cost effective bark beetle research to find a biological control.

II OTHER PERSONNEL ITEMS FOR MANAGERS TO CONSIDER

The present black book proposal the Ministry of Forests has developed is an excellent idea. The state-of-the-art of the beetle attack in all TSA's must be developed. The volume losses and an annual accountable plan of attack must be prepared by government and industry. This plan must be reviewed annually by government and industry to see how each participant performed.

Wave a red flag if nothing is being done. It probably won't go away. Industry, government and politicians must be brought in if nothing is being done.

Get everyone together to discuss the problem. Entomologists, protection people, timber and industry personnel must jointly understand and react to the problem. It is impossible to understand the other's point of view without this type of discussion.

COST BENEFIT ANLAYSIS AND OTHER ECONOMIC DECISION-MAKING PROCESSES IN ASSESSING AND SELECTING BEETLE MANAGEMENT OPTIONS

T. Niemann[1]

Introduction

The title of this speech is rather long. I would prefer something simple like "Economics of Beetle Management," but this title is already in use for the whole panel. Let me differentiate, therefore, between my understanding of "economics" and the various concerns (and frustrations) which my fellow panel members are discussing. Their concerns lie with constraints on the management of beetle infestations: problems with contractual obligations, source and timing of funds, planning of timber development, manufacture and marketing of products, and the need for incentives to tackle beetle infestations. My concern is with the economic basis of beetle management -- how best to use scarce resources to control beetle infestations. Supposing for the moment that we could wish away the problems which concern my fellow panelists -- we would still need a clear idea of how to tackle the problem of beetle infestations in a sensible, economic way. I will describe an approach which answers this need.

Let me begin by summarizing a few points we all agree on: I can readily agree with Allan Dupilka that the potential economic impacts of mountain pine beetle are immense. I may disagree with his numbers, but not his conclusion. We heard earlier in this symposium that control of mountain pine beetle, in some degree, is possible but expensive. We also heard that several control options, at various costs, are available.

Consideration of these points raises two main economic questions:

1) How much money should be spent on control, overall; and,

2) Which control options make the best use of available funds?

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Answering even one of these questions fully is not possible, as will become clear shortly, but some interesting observations can be made. I will first discuss the problems of setting an overall budget. Then I will examine some operational choices from an economic perspective.

Just before launching into these two topics, I want to say that my main aim in this presentation is to introduce three principal points:

1) Volumes "at risk" are not the main economic concerns. It is the volume which can be "saved" from mountain pine beetle which is important;

2) Uncertainty about the likely spread of mountain pine beetle and the efficacy of control measures creates severe difficulties for economic decision-making. Reducing that uncertainty could greatly influence both the level of funds for control and the allocation of these funds; and,

3) The least expensive control action, per unit of timber saved, is the one to use first.

Let's examine where and how these points apply to the two main economic questions.

Setting an Economically Appropriate Budget

In British Columbia, budgets for mountain pine beetle control are approved by Cabinet -- the ministers of the government. Forest managers can only hope to influence Cabinet decisions with information provided in a variety of documents, such as the recently published Forest and Range Resource Analysis (1984) and the submission to Cabinet requesting emergency funding for control of mountain pine beetle.

Can we help Cabinet by presenting better information? Certainly. This will involve better estimates by entomologists, forest planners and economists.

For my part, I do intend to make "better" guesses today. As I said, the uncertainties involved are great and the available information is far from complete. But I can offer a suggestion on making presentations more useful to Cabinet.

Cabinet wants to know what it is buying when it sets a budget. It has to justify expenditures for beetle control, based on expected reductions of impacts from mountain pine beetle -- the difference between expected impacts in the case of doing nothing and expected impacts in the case of taking control action.

The difference in impacts is measured in terms of the volume of pine saved. People may cleverly translate this into numbers of jobs, stumpage, contributions to gross domestic product, company profits and other measures. Rather than get side-tracked in the details of developing these figures, I want to emphasize the first of my three main points: It is the volume of pine saved by control actions that is important; not the volume "at risk."

To justify control expenditures on the basis of volumes "at risk" is wrong for several reasons:

- some susceptible pine timber is excluded from harvest for reasons other than the mountain pine beetle;

- it is unlikely that all the susceptible pine timber will be killed;

- of the timber that is likely to be killed, some can be harvested before or during an infestation;

- in some situations, timber of another species may be available in place of the pine actually lost; and, perhaps most importantly,

- we cannot totally prevent losses of timber to the mountain pine beetle, no matter how much is spent on control.

I submit, therefore, that the entomologists and forest planners among us should concentrate their analysis on what and how much timber can be saved.

This is made difficult by the great uncertainty of the future expansion of mountain pine beetle, which depends on such vagaries as the climate. Unfortunately, the uncertainty of successful control is also great.

In light of these uncertainties, the sophisticated economic process of cost benefit anaysis is hardly worth the trouble. Cost benefit analysis assesses net effects on society -- it is neither as simple nor as universally applicable as is popularly believed. I do not intend to elaborate on it here, except to say that the usefulness of its application to the mountain pine beetle problem would probably be overwhelmed by the great uncertainty of the data used in the analysis.

Uncertainty of data leads to my second main point: The uncertainties surrounding management of mountain pine beetle are great, and attempts should be made to reduce them. Reducing the uncertainties could significantly improve the reliability of economic information given to Cabinet, and thereby greatly improve Cabinet's ability to set an "economically appropriate" budget for mountain pine beetle control.

To conclude this discussion on setting budgets, I would like to emphasize that we who are involved in pest control, whether operationally, in research or in economic analysis, can only influence the decisions of Cabinet. We cannot make the decision on how large the budget will be. We should therefore concentrate on making the best use of the funds available to us.

Making the best use of available funds

When I was first invited to speak here, I was asked to deal with the question: "Are we doing the right things?" It sounds easy, but covers a lot of ground.

I decided not to tackle the complex problem of long term prevention of future infestations. Long term control methods include the creation of forests with mosaics of stands of different ages and species; the adjustment of rotation lengths so that harvest precedes infestation; and the enhancement of biological controls which could keep the beetle at low endemic population levels in the future. Long term controls may work well, but as yet, little is known about the costs of implementing them or the results which can be expected.

Instead, I chose to concentrate on the immediate problem of current infestations: forest and pest managers have to decide which of several control options to apply to each mountain pine beetle infestation.

The basic control options available are:

1) DO NOTHING (and suffer whatever consequences).
2) REDIRECT HARVEST in accessible areas to include infestations.
3) DISPOSE OF SINGLE TREES (utilize or fall and burn infested trees).
4) PROVIDE ACCESS AND HARVEST previously inaccessible, infested areas.
5) PROVIDE ACCESS, HARVEST AND DISPOSE OF SINGLE TREES in previously inaccessible, infested areas.
6) PHEROMONES (in conjunction with one of the above options).
7) BROADCAST BURN infested areas.

A criterion is needed to choose rationally which mix of control options makes the best use of available funds. Several such criteria exist.

One well-known criterion is the minimization of "cost plus loss". This criterion is typically used for fire control. The control costs and expected resource losses are added up for each possible mix of control actions and the mix with the lowest total (the lease painful mix) is selected. Calculating this can be a lot of trouble, due to the theoretical problem of attaching a value to the various resources that are lost and due to the amount of number-crunching involved.

I recommend use of another, simpler criterion: "Getting the best bang for your buck." This is my third main point: You start with the cheapest control action (the biggest bang per buck) and proceed to a lesser bang only if you have another buck left. The "bang" I'm interested in here is the volume of timber that is saved for a mill, instead of being lost to mountain pine beetle.

Think of it as buying timber as cheaply as possible from a store that is run by the mountain pine beetle.

Use of this criterion is known as analyzing cost-effectiveness, not cost benefit analysis. Each control action is evaluated by spreading the cost of control over the volume of pine which is expected to be saved by the control action. This gives us a cost per cubic metre (m^3) which describes the expected cost-effectiveness of that control action.

A practical procedure would involve picking the most cost-effective control action for each infestation; ranking all infestations in order of increasing cost per unit of timber saved ("bought") from the mountain pine beetle; and applying the available funds, starting from the top of the list, until no funds remain. Economists call this "allocating funds in order of decreasing cost-effectiveness."

Armed with this simple, useful criterion, we can now return to the list of basic control options:

The DO NOTHING option has no cost and saves no timber. It does not register in our measure of cost-effectiveness. If the expected volume losses from a particular infestation are so small, so remote or so poor in quality as to be considered unimportant, this option may be considered on the basis of its lack of cost. A risk remains, however, that beetles may migrate from this area to other areas which do contain valuable timber.

In areas with access, the REDIRECT HARVEST option may also have no cost, but may save substantial amounts of timber if it stops or slows the spread of mountain pine beetle. Adjustment of harvest plans may incur some costs. For example, harvesting in smaller cutblocks so as to control more infestations with a given harvest level, may involve some loss of harvesting efficiency (a cost that is difficult to ascertain) and some extra movement of equipment between cutblocks. Such costs are probably safe to ignore in most situations. The low or non-existent cost of controlling mountain pine beetle through redirecting harvest in already accessible areas, combined with the substantial volumes that may be expected to be saved, makes this the most cost-effective option. It is good to see it being used.

The DO NOTHING and REDIRECT HARVEST options are useful only if the wood to be saved does not warrant a costly effort, or if access and harvest capacity exist. Unfortunately, the wood to be saved is often valuable and quick harvest is often not feasible. In these situations, other options need to be considered, and use of the cost-effectiveness criterion becomes non-trivial.

I want to show how the cost-effectiveness criterion can help in the selection of options such as DISPOSE OF SINGLE TREES, PROVIDE ACCESS AND HARVEST, and PROVIDE ACCESS, HARVEST AND DISPOSE OF SINGLE TREES.

First, however, we have to recognize that mountain pine beetle infestations are very dynamic. The rate of expansion of an infestation varies considerably, depending on climate, topography, stand condition and the stage of infestation.

Figure 1 shows an increase in red top trees of 1.4 for every one in the previous year. This is a conservative estimate of the average rate of expansion in this area, and is very low relative to the 30:1 rate which can occur. For the remainder of my talk, please keep in mind that this assumed rate of expansion and other assumptions I will use have a great effect on the outcome of the economic analysis.

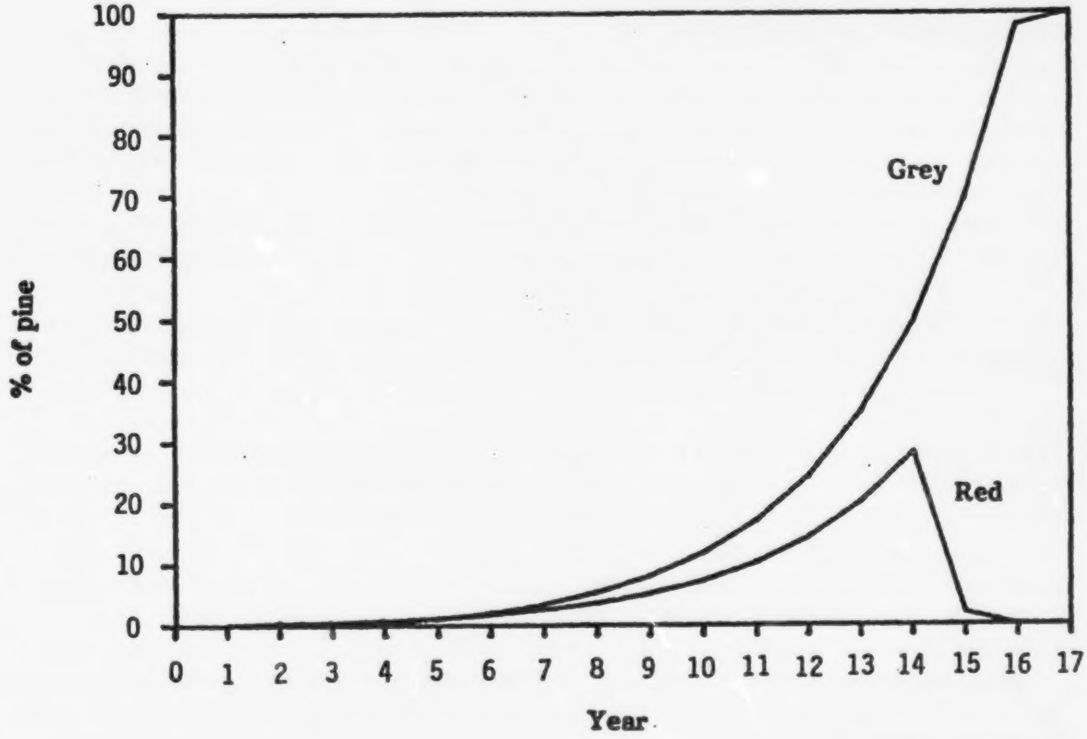

Figure 1. Expansion of an infestation at an annual rate of 1.4:1, showing the annual percentage of pine which has red-tops and the cumulative percentage of pine which is grey and no longer commercially harvestable. Based on Table 1A, Appendix I.

By using percentage of pine on the Y-axis, this graph can be thought of as representing either: 1) the volume of pine which is commercially harvestable; or, 2) the number of susceptible stems in a forest unit. I will be using the two measures interchangeably, because they represent virtually the same effect. The forest unit could be a large stand, small watershed, or a large watershed newly subjected to infestation. The lower curve shows the ANNUAL percentage of trees which have red tops. Based on a very small infestation of 0.5% of the trees in year 1, the curve starts in year 2, when the trees turn red. At this point the curve represents only one red tree per hectare in a stand with 200 merchantable (susceptible) trees per hectare. The infestation reaches the 5% level (10 trees per hectare) in year 9 and peaks five years later. I stress that this is based on the assumed rate of expansion. Infestations can and often do peak in as little as two or three years after the 5% level.

The CUMULATIVE impact, in terms of non-commercial, grey trees with loose bark and checking is shown in the upper curve of Figure 1. This curve shows the sum of trees that were red two or more years earlier. Essentially all the pine reaches this condition only seven years after 5% of the pine trees have red tops.

I conclude from Figure 1 that, even with a relatively slow rate of expansion, the economic effects occur quickly and there is little time for useful action. If no control action is taken after an infestation takes hold, the harvestable timber is eliminated swiftly.

In Figure 2 the DO NOTHING line shows the percentage of harvestable pine volume remaining in each year if no control action is taken. This is the inverse of the CUMULATIVE Line for grey trees in Figure 1.

The DISPOSE OF SINGLE TREES (YEAR 8) line in Figure 2 shows the expected outcome if felling and burning begins in the winter of year 8. During the preceding summer, just under 4% of the pine turn red. That's only 7 or 8 trees per hectare in the assumed stand of 200 susceptible, commercial trees per hectare.

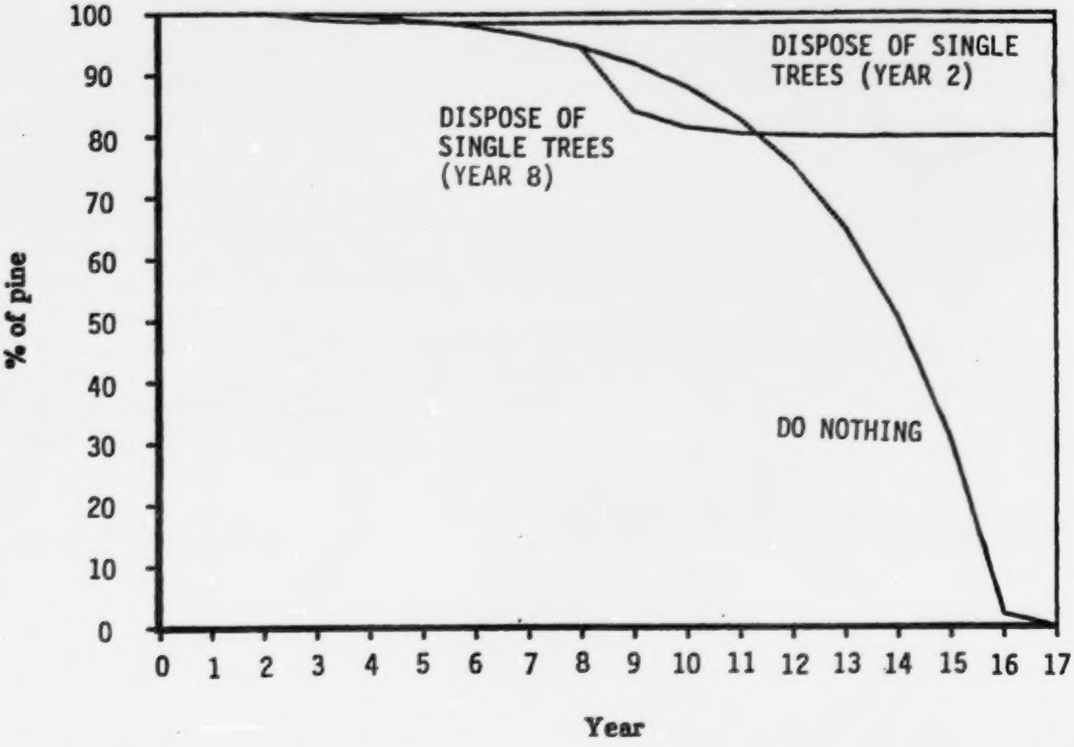

Figure 2. Harvestable pine remaining under the DO NOTHING and DISPOSE OF SINGLE TREES options, with control action beginning in years 2 and 8. Based on Table 2, Appendix I.

The expected outcome of felling and burning is based on disposal of all red top trees and 75% of the green infested trees in each year, starting with year 8. It takes only two years of this to bring the number of red top trees down to 0.5% (equivalent to year 2), but the control action is continued for another three years, virtually eradicating mountain pine beetle. In practice, felling and burning is not likely to be this effective, since continued immigration of beetles from surrounding stands or watersheds can be expected.

The third line in Figure 2, DISPOSE OF SINGLE TREES (YEAR 2), shows the expected outcome if felling and burning begins in the winter of year 2. Assuming conventional detection methods, this is the first possible opportunity for control in this example, since the initial infestation of 0.5% in year 1 only because visible as red top trees in the summer of year 2.

The distance between the DO NOTHING line and each of the DISPOSE OF SINGLE TREES lines represents the amount of commercial pine saved by control action. It is easy to see that if the assumptions used are reasonable, then felling and burning may provide excellent results for holding (saving) timber for later harvest. It is also easy to see that felling and burning in year 8 saves at most 80% of the pine, while catching the infestation six years earlier may save 98% of the pine.

In the Nilkitkwa Area (most of Supply Block C in the Bulkley Timber Supply Area), 80% of the pine amounts to about 2.5 million m^3. This is clearly a lot of timber to "buy" from the mountain pine beetle, and some control effort is quite probably worthwhile.

Before felling and burning, I would ask several questions: Can this control method be relied upon to hold timber for many years? How much does it cost? Could timber be saved less expensively by using other options? I will address each question in turn.

The DISPOSE OF SINGLE TREES option cannot be relied upon to hold the timber for 10 to 15 years, since further immigration of beetles can be expected. The volume saved will probably be less than the 80% or 98% mentioned.

I will calculate costs based on the assumption of no further immigration, as this makes the presentation of the analysis far simpler. Since further immigration is likely, this calculation will establish a minimum cost estimate.

The cost per m^3 saved depends on how early in the course of the infestation the control action begins, as this affects both the amount of effort required and the volume saved, over which control costs can be spread.

Two lines in Figure 3 show the cost per m^3 of pine saved by the DISPOSE OF SINGLE TREES options, when felling and burning begins in the winter of year 8 or year 2.

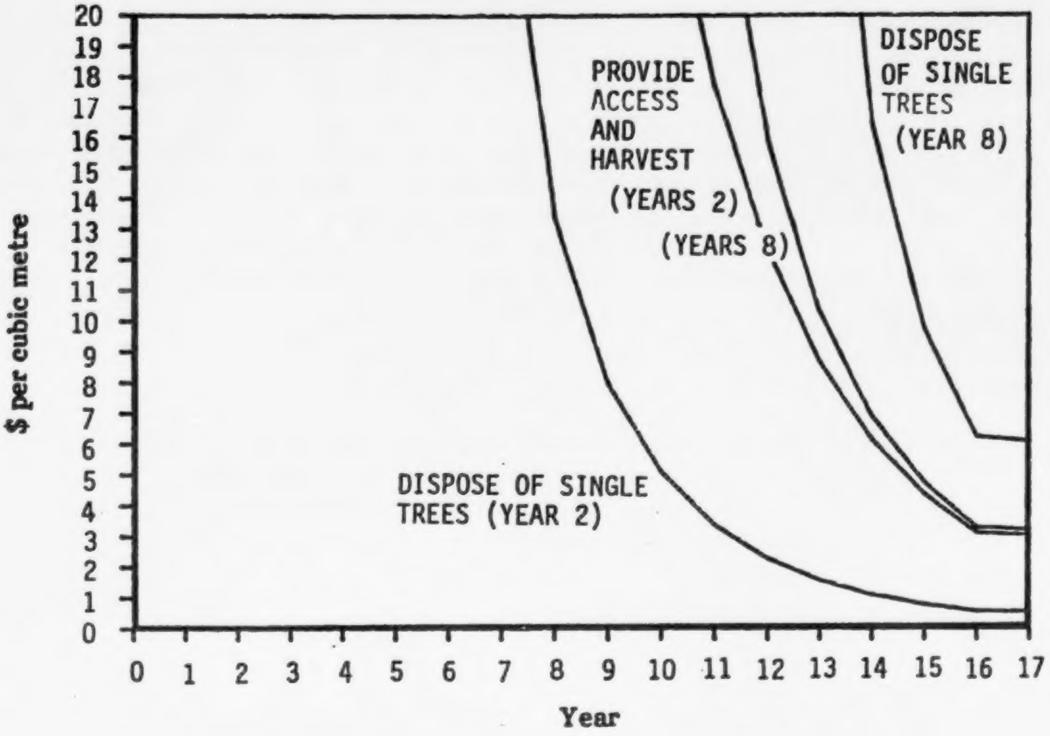

Figure 3. Cost of pine saved, relative to the DO NOTHING option, under the DISPOSE OF SINGLE TREES and PROVIDE ACCESS AND HARVEST options, with control action beginning in years 2 and 8. Based on Table 4, Appendix I.

The cost per m^3 drops rapidly, as the volume saved relative to the DO NOTHING option increases. It stabilizes at a final minimum cost determined by the maximum volume saved (80% or 98%, respectively) and the unit cost of the control action. I have used a felling and burning cost of $25.00 per tree, which amounts to $33.33/$m^3$, assuming 0.75 m^3 per tree.

The minimum cost of the DISPOSE OF SINGLE TREES (YEAR 8) option is about $6/$m^3$ for the 80% of pine saved. By contrast, the minimum cost of the DISPOSE OF SINGLE TREES (YEAR 2) option is only about $0.50/$m^3$. This drop in the cost of control, to only one tenth the cost of the same option exercised six years later, is due to the smaller control action required and the greater total volume saved.

In Figure 3, I have also shown the cost of the PROVIDE ACCESS and HARVEST option, for harvests beginning in year 8 and year 2. This option provides access earlier than planned for, in the absence of beetle infestations, and brings the mountain pine beetle under control with judiciously located cutblocks. It permits utilization of infested timber before it becomes non-commercial and stops the spread of infestation. I have assumed that the same number of green infested and red trees can be harvested as are felled and burned in the DISPOSE OF SINGLE TREES option.

The PROVIDE ACCESS AND HARVEST option differs from the DISPOSE OF SINGLE TREES option in that the infested trees become part of the volume saved and that an imputed cost is used, rather than an out-of-pocket expenditure. Since access and harvest were intended at some future point, even in the absence of beetle infestations, the total cost of providing access and harvesting cannot be attributed to beetle management. The cost of the PROVIDE ACCESS AND HARVEST option is an imputed interest charge on the funds needed for developing access, based on the number of years that construction is advanced for beetle control. For this example, I have used a fixed development cost equivalent to $\$2/m^3$ of pine available before infestation, and an interest rate of 8% applied over 12 years. Once again, the cost of control is spread over the volume of harvestable pine saved, relative to the DO NOTHING option.

The minimum cost of the PROVIDE ACCESS AND HARVEST (YEAR 8) option is about $\$3/m^3$, or about half of the $\$6/m^3$ minimum cost for the DISPOSE OF SINGLE TREES (YEAR 8) option. However, if detection and control action begin in year 2, the minimum cost of the PROVIDE ACCESS AND HARVEST (YEAR 2) option is again about $\$3/m^3$, but is about six times the $\$0.50/m^3$ minimum cost of the DISPOSE OF SINGLE TREES (YEAR 2) option.

Clearly, the choice of the least expensive control method depends on the stage of the infestation at the time of detection, or rather, the time that control begins. Figure 4 shows how the minimum costs of the DISPOSE OF SINGLE TREES and PROVIDE ACCESS AND HARVEST options rise if action is taken later in the course of an infestation. It shows the minimum costs, in year 17, for beginning control in year 2 through year 10 of an infestation. This includes the end point of each curve in Figure 3.

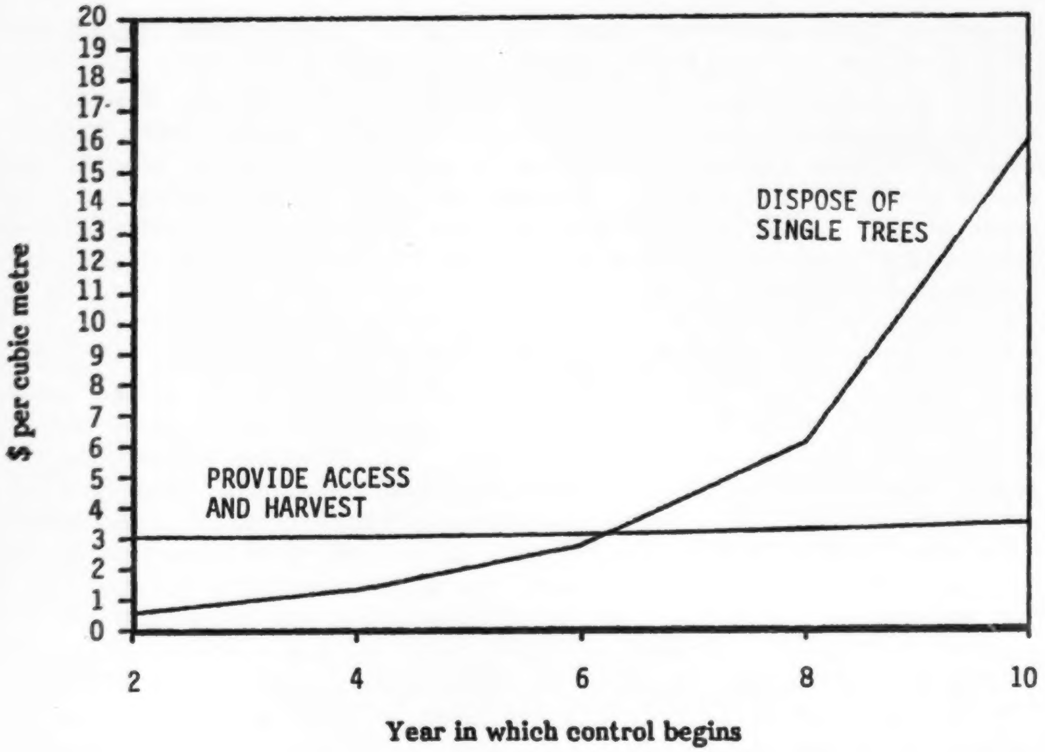

Figure 4. Minimum cost of pine saved, relative to the DO NOTHING option, under the DISPOSE OF SINGLE TREES and PROVIDE ACCESS AND HARVEST options, with control actions beginning in years 2, 4, 6, 8, and 10. Based on Table 5, Appendix I.

The minimum cost of the DISPOSE OF SINGLE TREES option starts lower, but rises steeply and exceeds the cost of the PROVIDE ACCESS AND HARVEST option beyond year 6. The minimum cost of the PROVIDE ACCESS AND HARVEST option is stable near $\$3/m^3$ for the first ten years of an infestation. Considering that further immigration of beetles can be expected to increase costs for both options, and that an epidemic may expand much more quickly after year 8, both options could cost far more than shown in Figure 4, for action beginning in years 8 and 10.

In Figure 4, it is easy to see that various lead times for building roads in the PROVIDE ACCESS AND HARVEST option do not greatly change the minimum cost. For example, whether road construction takes two or four years following a decision to act in year 4, the appropriate costs are nearly the same, reading from year 6 and year 8, when beetle control by harvesting begins.

In some cases, it may appear best to combine the PROVIDE ACCESS AND HARVEST option with the DISPOSE OF SINGLE TREES option.

While this PROVIDE ACCESS, HARVEST AND DISPOSE OF SINGLE TREES option will probably save the most pine volume, the cost per m^3 saved may be too high. With a two year lead time for providing access, most of the single tree disposal would occur while the access is being constructed, so no saving can be expected on the cost of single tree disposal. The cost of early access can therefore be considered simply as an additional cost which provides some insurance that the volume expected to be saved by single tree disposal is indeed harvested. This may be expensive insurance.

For example, this insurance costs almost $\$4/m^3$, based on spreading the cost of early access over the 80% of pine volume that remains after the DISPOSE OF SINGLE TREES (YEAR 8) option in Figure 2. Adding this to the $\$6/m^3$ minimum cost of the DISPOSE OF SINGLE TREES (YEAR 8) option brings the total cost of control, including insurance, to about $\$10/m^3$ of pine saved. This is very expensive.

The cost of controlling beetle infestations with the PROVIDE ACCESS, HARVEST AND DISPOSE OF SINGLE TREES option is probably acceptable only if the detection and control actions occur early, such as in year 2; or if access is advanced only a few years, thereby lowering the imputed cost of interest; or if the cost of early access can be attributed, in part or wholly, to some other reason such as needing the access to maintain a desirable species profile. Each situation should be looked at carefully, since the dynamics of both the pest and the controls affect the economic viability.

At this point, there are still two more basic control options: PHEROMONES and BROADCAST BURN. I will not try to analyze these. There is little data on the effectiveness of PHEROMONES, alone or in conjunction with other options. BROADCAST BURN seems easy to apply and analysze, but is rarely used due to topographic and hazard constraints. Let me simply say that the cost-effectiveness criterion could and should be applied to these options, just as to the other options.

I have discussed how to make the best use of available funds with control actions. I would like to mention briefly two more uses of funds which are often underrated: detection and research. These can save a lot of money.

For example, colour photographs may result in savings in ground detection costs that exceed their extra cost over black and white photos -- and the subsequent work on the ground can be far better, resulting in further savings because less control action is required on return trips. Infra-red photos could, if proven workable, shorten the detection period by one year, which would save on the order of $\$2/m^3$ of large volumes of pine saved.[2] Reliable stand hazard rating systems could help us avoid allocating funds to sites where the probability of successful control is unreasonably low. Similarly, a thorough investigation of the effectiveness of brood removal on ridge tops may help us avoid wasteful expenditures. By obtaining and applying the better information available through increased detection and research, we can improve the overall effectiveness of mountain pine beetle management. This may well be the most cost-effective way to spend a large part of our limited funds.

Summary

I would like to finish by restating the two main economic questions:

1) How much money should be spent on control, overall; and,

2) Which control options make the best use of avaiable money?

Since we can only influence Cabinet's decision-making on funding, we should concentrate on making the best use of available money. In this regard, the three principal points that I have woven throughout this presentation will be helpful:

First, let's talk about the volume that we can reasonably expect to save. Volumes "at risk" are not the main economic concern. It is the volume which can be "saved" through control efforts that counts;

Second, let's try to reduce the uncertainty surrounding both the pest and controls of it, as this will help both the determination of an appropriate budget and the allocation of our fixed funds; and,

Finally, let's make the best use of our time and available funds by doing first whatever is expected to save timber at the lowest cost per unit of timber saved.

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[2] In Figure 4, compare costs for the DISPOSE OF SINGLE TREES option in year 7 and year 8.

APPENDIX I

TABLES

TABLE 1A. Dynamics of a mountain pine beetle infestation under the DO NOTHING option.

Year	Green Uninfested	Green Infested*	Red	Red/Grey Tight Bark	Grey Loose Bark
		- - - - - - - - - - (% of pine in watershed) - - - - - - - - - -			
0	100.0				
1	99.5	0.5			
2	98.8	0.7	0.5		
3	97.8	1.0	0.7	0.5	
4	96.4	1.4	1.0	0.7	0.5
5	94.5	1.9	1.4	1.0	1.2
6	91.8	2.7	1.9	1.4	2.2
7	88.1	3.8	2.7	1.9	3.6
8	82.8	5.3	3.8	2.7	5.5
9	75.4	7.4	5.3	3.8	8.2
10	65.1	10.3	7.4	5.3	11.9
11	50.6	14.5	10.3	7.4	17.2
12	30.4	20.2	14.5	10.3	24.6
13	2.0	28.3	20.2	14.5	34.9
14		2.0	28.3	20.2	49.4
15			2.0	28.3	69.6
16				2.0	98.0
17					100.00

*Initial infestation is 0.5%. Annual rate of expansion is 1.4:1.

TABLE 1B. Dynamics of a mountain pine beetle infestation under the DISPOSE OF SINGLE TREES and PROVIDE ACCESS AND HARVEST options, with control action beginning in year 2.

Year	Green Uninfested	Green Infested*	Red	Red/Grey Tight Bark	Grey Loose Bark	Disposed of or Harvested**
	- - - - - - - - - -	(% of pine in watershed)	- - - - - - - - -			
0	100.0					
1	99.5	0.5				
2	98.8	0.7	0.5			
3	98.6	0.2	0.2			1.0
4	98.5	0.1	0.1			1.4
5	98.4					1.6
6	98.4					1.6
7	98.4					1.6
8	98.4					1.6
9	98.4					1.6
10	98.4					1.6
11	98.4					1.6
12	98.4					1.6
13	98.4					1.6
14	98.4					1.6
15	98.4					1.6
16	98.4					1.6
17	98.4					1.6

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* Initial infestation is 0.5%. Annual rate of expansion is 1.4:1.

** Beginning in the winter of year 2, all red and red/grey trees and 75% of green infested trees in each year are disposed of or harvested by the next year. The remaining 25% of green infested trees in each year become red and result in 1.4 times as many new green infested trees in the next year.

TABLE 1C. Dynamics of a mountain pine beetle infestation under the DISPOSE OF SINGLE TREES and PROVIDE ACCESS AND HARVEST options, with control action beginning in year 8.

Year	Green Uninfested	Green Infested*	Red	Red/Grey Tight Bark	Grey Loose Bark	Disposed of or Harvested**
	- - - - - - - - - -	(% of pine in watershed)			- - - - - - - - - -	
0	100.0					
1	99.5	0.5				
2	98.8	0.7	0.5			
3	97.8	1.0	0.7	0.5		
4	96.4	1.4	1.0	0.7	0.5	
5	94.5	1.9	1.4	1.0	1.2	
6	91.8	2.7	1.9	1.4	2.2	
7	88.1	3.8	2.7	1.9	3.6	
8	82.8	5.3	3.8	2.7	5.5	
9	81.0	1.8	1.3		5.5	10.4
10	80.3	0.6	0.5		5.5	13.1
11	80.1	0.2	0.2		5.5	14.1
12	80.0	0.1	0.1		5.5	14.4
13	80.0				5.5	14.5
14	80.0				5.5	14.5
15	80.0				5.5	14.5
16	80.0				5.5	14.5
17	80.0				5.5	14.5

* Initial infestation is 0.5%. Annual rate of expansion is 1.4:1.

** Beginning in the winter of year 2, all red and red/grey trees and 75% of green infested trees in each year are disposed of or harvested by the next year. The remaining 25% of green infested trees in each year become red and result in 1.4 times as many new green infested trees in the next year.

TABLE 2. Harvestable pine remaining under the DO NOTHING, DISPOSE OF SINGLE TREES and PROVIDE ACCESS AND HARVEST options, with control action beginning in years 2, 4, 6, 8 and 10.

		DISPOSE OF SINGLE TREES**					PROVIDE ACCESS AND HARVEST***				
Year	DO NOTHING*	Year 2	Year 4	Year 6	Year 8	Year 10	Year 2	Year 4	Year 6	Year 8	Year 10
	- - - - - - - - - - (% of pine in watershed) - - - - - - - - - -										
0	100	100	100	100	100	100	100	100	100	100	100
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	99	100	100	100	100	100	100	100	100	100
4	100	99	100	100	100	100	100	100	100	100	100
5	99	98	97	99	99	99	100	100	99	99	99
6	98	98	96	98	98	98	100	100	98	98	98
7	96	98	96	93	96	96	100	100	98	96	96
8	95	98	96	91	95	95	100	100	98	95	95
9	92	98	96	91	84	92	100	100	98	95	92
10	88	98	96	90	81	88	100	100	98	95	88
11	83	98	96	90	80	68	100	100	98	95	88
12	75	98	96	90	80	62	100	100	98	95	88
13	65	98	96	90	80	61	100	100	98	95	88
14	51	98	96	90	80	60	100	100	98	95	88
15	30	98	96	90	80	60	100	100	98	95	88
16	2	98	96	90	80	60	100	100	98	95	88
17		98	96	90	80	60	100	100	98	95	88

* All pine other than that with grey loose bark, from Table 1A.

** All pine other than that with grey loose bark and that disposed of, from Tables 1B and 1C and similar tables for years 4, 6 and 10.

*** All pine other than that with grey loose bark, from Tables 1B and 1C and similar tables for years 4, 6 and 10.

TABLE 3. Pine saved, relative to the DO NOTHING option, under the DISPOSE OF SINGLE TREES AND PROVIDE ACCESS AND HARVEST options, with control action beginning in years 2, 4, 6, 8 and 10.

	DISPOSE OF SINGLE TREES*					PROVIDE ACCESS AND HARVEST**				
Year	Year 2	Year 4	Year 6	Year 8	Year 10	Year 2	Year 4	Year 6	Year 8	Year 10
	(% of pine in watershed)									
0										
1										
2										
3	-1									
4	-1					1				
5	0	-2				1	1			
6	1	-2				2	2			
7	2	-1	-4			4	3	1		
8	4	1	-3			5	5	3		
9	7	4	-1	-8		8	8	6	3	
0	10	8	2	-7		12	11	10	6	
11	16	13	8	-2	-15	17	17	15	12	5
12	23	20	15	5	-13	25	24	22	19	13
13	33	31	25	15	-5	35	34	33	29	23
14	48	45	40	29	9	49	49	47	44	37
15	68	65	60	50	29	70	69	67	64	58
16	96	94	88	78	58	98	98	96	93	86
17	98	96	90	80	60	100	100	98	95	88

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* The difference between harvestable pine remaining under the DISPOSE OF SINGLE TREES and DO NOTHING options, from Table 2.

** The difference between harvestable pine remaining under the PROVIDE ACCESS AND HARVEST and DO NOTHING options, from Table 2.

TABLE 4. Cost of pine saved, relative to the DO NOTHING option, under the DISPOSE OF SINGLE TREES and PROVIDE ACCESS AND HARVEST options, with control action beginning in years 2, 4, 6, 8 and 10.

	DISPOSE OF SINGLE TREES*					PROVIDE ACCESS AND HARVEST**				
Year	Year 2	Year 4	Year 6	Year 8	Year 10	Year 2	Year 4	Year 6	Year 8	Year 10
	- - - - - - - - - - (% of pine in watershed) - - - - - - - - - -									
0										
1										
2										
3										
4						607.27				
5						253.03	433.76			
6	82.61					139.28	180.73			
7	26.36					85.48	99.49	221.31		
8	13.46	101.61				55.48	61.06	92.91		
9	7.89	32.37				37.20	39.63	50.76	112.91	
10	5.08	16.51	101.61			25.46	26.57	31.15	47.05	
11	3.36	9.78	32.37			17.66	18.18	20.22	25.90	57.61
12	2.29	6.23	16.51	101.61		12.35	12.61	13.56	15.89	24.00
13	1.58	4.13	9.78	32.37		8.70	8.82	9.28	10.32	13.21
14	1.10	2.80	6.22	16.49	101.21	6.15	6.21	6.43	6.91	8.10
15	0.77	1.93	4.12	9.78	32.33	4.36	4.39	4.50	4.73	5.26
16	0.55	1.35	2.80	6.22	16.50	3.10	3.11	3.17	3.28	3.53
17	0.53	1.32	2.74	6.07	15.97	3.04	3.05	3.10	3.21	3.45

* The cost of tree disposal is spread over the pine saved, from Table 3:

$$\frac{(\text{\% disposed of})}{(\text{\% pine saved})} \times \frac{(\$25/\text{tree})}{(0.75\ \text{m}^3/\text{tree})} = \$/\text{m}^3 \text{ of pine saved}$$

** The imputed cost of borrowing funds with which to provide earlier access is spread over the pine saved, from Table 3. An interest cost of 8% over 12 years is assumed:

$$\frac{(\$6\ \text{million})}{(\$3\ \text{million m}^3)} \times \frac{(100\%\ \text{of pine})}{(\%\ \text{pine saved})} \times (1.08^{12} - 1) = \$/\text{m}^3 \text{ of pine saved}$$

TABLE 5. Minimum cost of pine saved, relative to the DO NOTHING option under the DISPOSE OF SINGLE TREES and PROVIDE ACCESS AND HARVEST options, with control action beginning in years 2, 4, 6, 8 and 10.

Year in Which Control Begins	DISPOSE OF SINGLE TREES*	PROVIDE ACCESS AND HARVEST**
	($ per cubic metre)	
2	0.53	3.04
4	1.32	3.05
6	2.74	3.10
8	6.07	3.21
10	15.97	3.45

* Cost of pine saved under the DISPOSE OF SINGLE TREES option, from year 17 in Table 4.

** Cost of pine saved under the PROVIDE ACCESS AND HARVEST option, from year 17 in Table 4.

PEST MANAGEMENT DECISION WITH REGARDS TO SHORT AND LONG TERM WOOD SUPPLY

B. Swan[1]
(Presented by P. Ogawa[2])

Objectives

1. Minimize loss of merchantable wood
2. Maximize utilization of forest resource
3. Minimize detrimental effect of infestation on the Annual Allowable Cut
4. Protect the forest land resources e.g., timber, water, recreation, etc.

Effect of Mountain Pine Beetle Infestations on Industrial Operations

Dislocation of previous plans

a) Lack of access is a key factor.
b) Increased road building program.
c) Increased road costs due to using green roads before chance to settle. They require more gravel, etc. Also increased demand for road construction during the winter logging season.
d) Higher unit cost of road due to decreased volume per hectare on account of dead wood (grey-attacked pine).
e) Poor road conditions increase trucking costs and water sedimentation.
f) Lack of lead time for planning requires extra staff and additional cost.

Increased Logging Costs

a) Lower volume per hectare due to non-merchantable wood.
b) Increased breakage.
c) Logging certain sites at the wrong time of year.

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[1] Brodie Swan, Woods Manager, Revelstoke Sawmills, Ltd., Radium Hot Springs, B.C.

[2] Pat Ogawa, Woods Manager, Houston Forest Products, Houston, B.C.

Effect on the Sawmill

a) Undesirable log mix, with regards to both size and species.
b) Shortage of larger logs for head-rig
c) Effects on sawmill production.
  - Increased breakage.
  - Increased low grade lumber and trim loss.
  - Net dollar return to sawmill decreases, the price of two by ten versus two by four, there is a much larger percentage of two by four lumber produced from MPB infested timber.

  - There is a detrimental effect on the kiln operation because of increased fall down due to variation in lumber moisture content, e.g. the lumber becomes too dry and it breaks in the planer.

  - Industry must be assured of a sustainable increase in volume of wood before adding plant capacity, e.g. industry performance is subject to market conditions. Must produce a product that can be sold.

Planning

1. Identify the problem. Add the solution to the problem and that equals the plan.

2. Must be able to react quickly to MPB outbreaks. Therefore, we must retain flexibility to deal with new outbreaks in the planning process and in the logging process, eg. use large cutting permit plans which encompass entire drainages.

Identify the Problem

a) Know the extent of the lodgepole pine resource.
b) Identify areas of infestaton.
c) Establish accurate volume estimates.
d) Set priorities. Criteria for setting priorities must be firmly established.

Salvage

- Stands losing appreciable volume unless harvested within six to twelve months.
- Stands losing appreciable volume if not salvaged within twelve to twenty four months.
- The next category is twenty four to thirty six months. We have found that grey-attack timber over three years old is not merchantable.

Control

- Remove green-attack pine.
- Remove stands of pine susceptible to attack.

Solution of Problem

1. Determine volume of lodgepole pine that the manufacturing plant can process annually.
2. Establish minimum requirements regarding timber size and quality for the manufacturing plants.
3. Determine the total and annual volumes of pine to be harvested in order to avoid loss of merchantable wood.
4. Establish cutting priorities.
5. Identify access requirements.
6. Expedite access construction on a priority basis.
7. Draw up five year plans to be updated annually.
8. Reduce time delay in harvesting. Net volumes and lumber recovery decrease in proportion to amount of time since attack.

Incentives

1. The industry requires appropriate incentives to encourage salvage control operations, as insect infestations create additional costs.

2. Industry operating in Crown timber requires incentive to harvest MPB damaged wood. There should be appropriate stumpage policies to encourage salvage operations.

3. Adequate appraisal allowances.

   - There should be relaxation of utilization standards for dead and defective wood. Under the stumpage policies there should be higher logging cost allowances to offset the increase in logging costs.

   - Higher sawmilling allowances to offset the increase in milling costs, lower lumber recovery factor and increased risk allowance due to higher percentage of lower grades and narrower widths of lumber.

   - There should be a provision for supplementary funds to offset added road building costs, insect surveys and inventory costs.

Longer Term Considerations

1. The present over-cutting in order to minimize loss of merchantable wood leads to future reduction in AAC. In the East Kootenays, rapid liquidation of future winter logging areas will affect future operations. Lodgepole pine usually grows on good winter logging ground in the East Kootenays in the valley bottoms.

2. Reforestation - Large areas of lodgepole pine harvest blocks require post-logging site treatment and reforestation. This requires a provision of additional funds and equipment for post-logging site treatment.

Conclusions

a) Short Term

- Minimize timber loss through adequate insect surveys and planning for prompt control and salvage harvest.
- Adequate advanced access to lodgepole pine stands.
- Create ability to react quickly to salvage and control requirements.

b) Long Term

- Install adequate plant capacity.
- Minimize future reduction in AAC by prompt post-logging site treatment and reforestation.
- Consider the effect of loss of future winter or summer operating areas through having to harvest timber on certain sites at the wrong time of year.

QUESTIONS

QUESTION: Are there any figures on the effectiveness of falling and burning?

LES SAFRANYIK: One of the conditions for direct control states that you have to be able to cover the control area within one or two years. Remember that the average B.C. rate of infestation increase is for each one tree infested this year, you'd get roughly two next year. That implies, among many other things, that if you cannot cut out at least half of the infested trees, you're losing it. The infestation gradually gets away from you, because the other half will produce more insects than what you can control. It does not mean, though, that the operation may not be useful as a holding action.

QUESTION: Do you actually think it makes sense to be cleaning up spots over a 10 km long drainage while there's still a huge reservoir 5 km away?

LES SAFRANYIK: Basically, as a holding action, I feel that direct control is a very worthwhile thing even in that situation. If you're basically close to a maximum utilization, then you have to slow the rate of depletion down. In situations where you have a large outbreak nearby, year after year you would have to clean up these small patches of infestation, simply because the likelihood is that they would be re-infested until the big infestation, collapses or burns itself out. Alberta had a very very large infestation south of a certain highway that was a source of beetles, resulting in constant re-invasion. They kept cleaning up their control zone, and now they hardly have any infested trees. I am convinced that it was worth it. It all depends on what value you put on the resource you're saving.

BOB MYAGAWA: You have to have a continuous program from year to year, just to pick up spots if you've got a large beetle reservoir sitting. And you've got to hit them hard and fast.

CLOSING REMARKS

R.F. DeBoo[1]

It's been a long two days and one thing comes to mind as we try to end on a positive note. Right from the start of this session, it was very clear that we have had a survey handle on the mountain pine beetle (MPB) for four decades, thanks to the perseverance of the Canadian Forestry Service (CFS). However, this information possibly may not have been used to its best advantage -- probably due to our limited capabilities and interests at the time. However, now we have moved from lodgepole pine being considered a "weed" species to its being a major commercial species within the past 1-2 decades.

Forty years of knowing beetles to 15 years of considering lodgepole pine to be an important species sets the stage. I can't see us affording to be pessimistic at all. Skeptics cannot be permitted regarding MPB. There are many things going, not so much to focus on the beetle, but to focus on pine. All of these good things have occurred because of MPB.

In the first panel, we couldn't have had a better condensed version of beetle biology. We heard about the importance of weather and host, and about the relationships between the two. We also heard about dispersal. These are the 3 key points when discussing beetles. We have a complex situation out there and we have to examine all the pieces. We're nowhere until we can join pest management with forest management.

Detection is the area of concern to most people, and the need to detect beetles early and properly was brought out as very important. From the persistant, conservative and dedicated approach of the CFS to the exotic and exuberant work of Peter Murtha, we will find things falling into place fairly soon. This conference will spawn serious discussion and important developments should come on-stream in the next couple of years. When talking of economy and efficiency of aerial photos etc., these discussions have shown their worth.

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[1] Robert F. Deboo, Manager, Pest Management, Forest Protection Branch, B.C. Ministry of Forests.

During the third panel it became clear that there are things we can do. Pest management needs the back-up of economists, planners, foresters and a whole lot of other people. We have a long list of opportunities, we have a wide selection of things to do, and we should be implementing these. We have got to show that we can start dropping the number of beetle-attacked trees and we must persevere.

The bottom line is what we heard from the fourth panel. We must be able to better express the dilemma and our losses, as well as our risks and our accomplishments. We must take a gamble and express our concern to the politicians, so that they can understand the problem in terms of losses to society, i.e. large economic losses, jobs, millions of cubic metres, mill production and so on. Our challenge is the refinement of the message and the way we report losses and successes.

Finally, we have both the responsibility and the obligation to acknowledge the problems and aim at the priorities in a coooperative and coordinated manner. There is both a long-term and a short-term approach, but the long-term is the ultimate solution.

On a closing note, this has been an excellent conference and it is apparent that we have to have another one soon. Thank you very much for coming.

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